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PHYSIOLOGY:
THE VITAL PROCESSES IN HEALTH

BY

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II.

PHYSIOLOGY: THE VITAL PROCESSES IN HEALTH.

By FREDERIC S. LEE, Ph. D.

INTRODUCTION.

The physiology of an organism treats of the healthy working of the organism. It deals with the living, acting body, with what the body does and how it does it. Anatomy can be studied best upon the dead body. Physiology, however, must be studied chiefly upon the living body, since in death the action ceases. The present sketch is devoted particularly to the physiology of man, but we must bear in mind that physiology is a very broad science and has to do with all living things, animals or plants. Only a limited range of observation and experimentation is possible upon the living human being, hence the work of the physiologist consists chiefly of work upon animals other than the human species. Human physiology consists largely of careful, well-guarded inferences from the results of such experimental work.

Man the Result of Evolution.

The reasonableness of such a method of inference is apparent when one accepts as a fact what is no longer doubted by scientific men—that the human species is both anatomically and physiologically a form that has been derived from other and lower species of animals. Such a belief gives a unity and harmony, not otherwise possible, to the facts of biology. Man is physiologically interesting in himself; he is physiologically more interesting when regarded as the latest and most complex product of a long ancestry reaching back through mammals, reptiles, fishes, and a long line of simpler animals, to the most primitive forms. The study of these animals is a study of the steps by which man has arrived at his present stage.

Like other animal bodies, the human body is a complicated machine, adapted for doing a great variety of work. The term "vital energy" is often heard—a term which indicates that the living body is something fundamentally different from other machines that are made of iron, or

steel, or brass. During the present century, however, it has been proved that all kinds of energy in inorganic nature—such as mechanical work, heat, light, and electricity—are only different forms of a universal energy. Moreover, it has been shown that "vital energy" is not distinct from other kinds, and that the actions of the living body—walking, swimming, flying, speaking, the circulation of the blood, and probably the activities of gland cells, of brain cells, etc.—are performed according to the same mechanical, physical, and chemical laws that apply to inorganic matter. The task of the physiologist consists, then, largely in a study of the mechanics, physics, and chemistry of the living body. The goal toward which he is pressing is a full understanding of the nature of life itself. It is unnecessary to say that that goal is still far distant.

Protoplasm the Physical Basis of Life.

A great advance that has taken place during the past sixty years is the proof that life is always associated with a certain visible material substance. This substance is called *protoplasm.* It occurs in muscles, glands, skin, brain, bone, nerves, and all the organs. *It is in fact the living substance of all parts of all living bodies.* It is always associated with lifeless substance, such as the fluid parts of a body, the mineral parts of bones, the hard substance of teeth, the nails, the hair, and the microscopic lifeless material that permeates all parts of every body. In its simplest form protoplasm is a colourless, jelly-like, nearly transparent substance, somewhat resembling raw white of egg. It is a mixture of several chemical substances; it has a variable composition, but always contains carbon, hydrogen, nitrogen, oxygen, and sulphur. It differs in appearance and composition in different parts of the body, the protoplasm of muscle being identical neither with that of gland cells nor with that of nervous substance.

Organs, Tissues, and Cells.

Dissection shows that a body is composed of definite parts, or *organs*, each of which, as we shall see, has a definite function to perform. Thus the heart, the stomach, the eye, the liver, and the brain are organs. Each organ has its own peculiar structure, but each is made up of comparatively few structural substances. These substances are called *tissues*, and each tissue—such as connective tissue, muscle tissue, fat tissue—has its own work to do. Examination of the tissues with the microscope shows that each is composed partly of lifeless substance, usually in small quantity, and chiefly of minute living particles of protoplasm, the *cells* (Fig. 1). Cells vary greatly in shape and size and in the work that they do, but in any one tissue they are similar in structure and function. The work of a body is the sum of the work of its individual cells, and the fundamental problems in physiology lead back to protoplasm and the cells.

Every human body consists at first of a single cell within the body of

the mother. In growth the single cell divides into two cells, the two into four, the four into eight, and the process continues until in the adult millions of cells exist. Along with the increase in number there occurs a differentiation in form and a division of labour among the various cells, such that some come to perform the various muscular movements, others prepare digestive substances, others remove waste matter from the blood, others control the breathing, still others do the thinking, some are affected

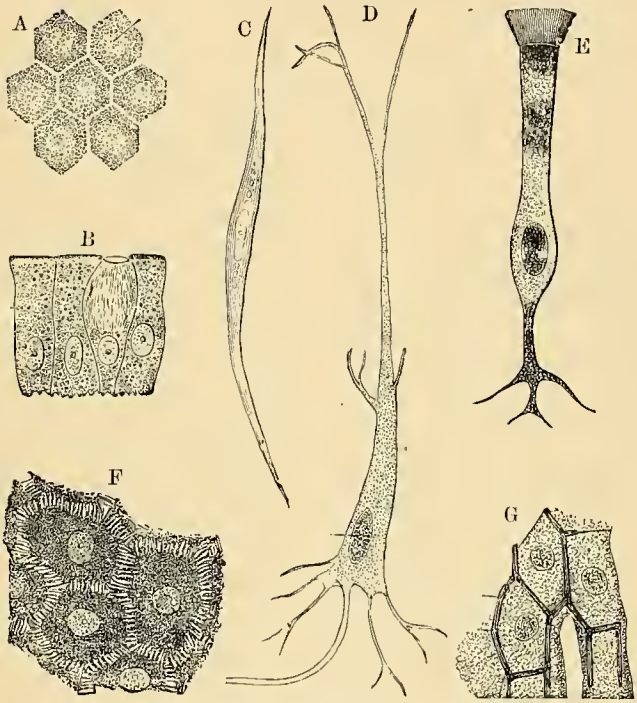

FIG. 1.—TYPICAL CELLS FROM THE HUMAN BODY.

Each cell consists of granular or striated protoplasm, and contains a denser protoplasmic mass, the nucleus. The nucleus is round or oval, and appears darker or lighter than the rest of the cell. A, seven pigment cells from retina (Schultze); B, four epithelium cells from intestine—one swollen with mucus represents a "goblet cell" (Frey); C, unstriped muscle cell (Arnold); D, nerve cell from brain (Gage); E, ciliated epithelium cell—the cilia constitute the brushlike upper end (Rosenthal); F, three "prickle-cells" from skin (Robinson); G, three gland cells from liver—the heavy dark lines represent bile ducts (Kölliker).

by waves of light, some by waves of sound, and thus we perceive that in this complicated human machine each part has its own work to do, and the division of labour is far-reaching.

Protoplasm is said to be irritable or excitable—that is, it is capable of being thrown into activity by proper stimuli. Every kind of cell, or tissue, or organ has its own natural method of stimulation and its own natural response or function. Every vital action is a response to some kind of stimulus.

The leading functions of the body, together with their chief agents, may be grouped as follows:

Functions.		Organs and other Agents.
Nutrition.	Alimentation.	Alimentary canal: consisting of mouth, œsophagus, stomach, small intestine and large intestine; liver; pancreas.
	Circulation ..	Blood system: consisting of heart, arteries, capillaries and veins; lymphatic system: consisting of lymphatic vessels and lymphatic glands; blood, lymph.
	Respiration..	Trachea, lungs.
	Metabolism..	All living cells.
	Excretion....	Lungs, kidneys and accessory organs, skin.
Motion.....		All muscles.
Co-ordination.....		Brain, spinal cord, nerves, sympathetic nervous system.
Activity of special senses..		Eye, ear, organs of smell, of taste, of touch, of temperature, and of muscular sensations.
Support.....		Bones, cartilage, connective tissue.
Reproduction.....		Female: ovaries and accessory organs. Male: testes and accessory organs.

CHAPTER I.

NUTRITION.

Like any other machine in action, the living human body constantly gives off energy to the outside world in the form of heat and mechanical work, and, moreover, its own material is being constantly used up. It requires food to replace these two losses of energy and substance. The story of nutrition is a long one. It tells how the body prepares for its use the food that is given to it (digestion); how the prepared food is taken into the distributing apparatus (absorption); how it is carried to the living cells (circulation); how it is used there for the production of new protoplasm, and how the protoplasm in action is destroyed, leaving waste matters (metabolism); and, finally, how the wastes, being harmful to the body, are removed from it (excretion). These subjects will now be considered in detail.

Section I.

ALIMENTATION.

Alimentation in General.

Alimentation consists of the two processes of digestion and absorption. Digestion comprises the chemical and physical changes which the food undergoes by way of preparation for entrance into the tissues, and for use by the living substance. Absorption is the process of the passage of digested food into the blood and lymph, whence it is carried to the tissues. Alimentation takes place in the alimentary canal (Fig. 2), which is a long tube

extending through the body, opening above at the mouth and below at the anus; its walls consist of muscle with glands, blood-vessels, and lymph-vessels. The successive parts of the canal are known as mouth, pharynx, œsophagus or gullet, stomach, small intestine and large intestine. To it are joined, by ducts, several large glands—namely, the three pairs of salivary glands, the pancreas, and the liver; all of these in their origin are outgrowths from the canal, but in the adult body they lie outside of its walls. The food enters at the mouth, and is propelled along the canal by the contraction of the muscular walls; the glands secrete—that is, manufacture and pour into the canal various fluids that differ in nature in various parts of the canal, and whose office it is to digest the food; the blood-vessels and the lymph-vessels, besides bringing blood and lymph to the walls of the canal, receive the digested food and bear it away to all parts of the body; the indigestible, the undigested, and the innutritious substances in the canal undergo chemical changes, and finally are expelled from the body as excrement.

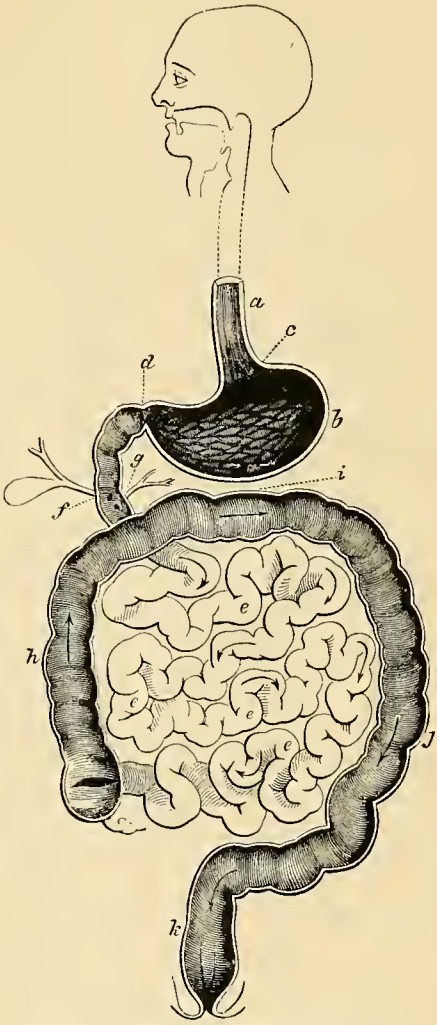

Fig. 2.—Human alimentary canal.

a, œsophagus; *b*, stomach; *c*, cardiac orifice; *d*, pylorus; *e*, small intestine; *f*, biliary duct and gall bladder; *g*, pancreatic duct; *h*, *i*, *j*, *k*, large intestine; *h*, ascending colon; *i*, transverse colon; *j*, descending colon; *k*, rectum. At junction of *e* and *h* is ileo-cæcal valve, below which is vermiform appendix. (Dalton.)

Food Stuffs.

The common foods, though apparently so different in character from each other, are found by chemical analysis to be mixtures of a small number of substances known as *food stuffs*. The most common food stuffs are *proteids* (the most important constituent of all meats, fish and eggs); *albuminoids* (such as gelatin; they are closely related to proteids, and hereafter will be included with them);

carbohydrates (such as starch and sugar, abundant in bread, pastry, and vegetables); *fats* (abundant in meats, butter, and milk); *water* and *salts* (such as table salt and numerous other salts). For a discussion of the characters and value of these various food stuffs the reader is referred to the article in this volume on *Hygiene.*

Digestion in General.

Water and the salts that are dissolved in the food are absorbed unchanged into the blood. Of the other food stuffs, proteids and carbohydrates are chemically changed by the digestive process, the former into closely related bodies called proteoses, peptones, and derivatives of the peptones, the carbohydrates mainly into a form of sugar called maltose, together with a small quantity of a starch called dextrin. By reason of the unsettled questions regarding the true nature of some of these digested substances, it will suffice hereafter to speak of all the products of proteid digestion simply as peptone, and of all the products of carbohydrate digestion as sugar. Contrary to what is found in most of the food stuffs, peptone and sugar are soluble, and hence when dissolved in the water of the food are fit for absorption. The digestion of the fats consists in part in changing them chemically into fatty acid, glycerin, and soap, and in part in simply breaking them up mechanically into minute droplets, this latter process being called emulsification; after these changes the fats are ready for absorption.

Digestive Fluids.

The digestive fluids are manufactured in the glands of the alimentary canal, and are poured out into it. They are five in number—viz., saliva, gastric juice, intestinal juice, pancreatic juice, and bile. Each consists chiefly of water together with a small quantity of dissolved solids, among which, except in the bile, is one or more of a peculiar class of bodies called *enzymes* or *unorganized ferments*, to which the digestive property of the fluids is due. The enzymes are peculiar chemical compounds, the exact constitution of which is unknown, but, when mixed with the food stuffs, they produce extensive chemical changes in the latter without being in themselves greatly altered.

Saliva is produced by the minute glands in the walls of the mouth and the three pairs of large salivary glands, the parotid, the submaxillary, and the sublingual (see *The Anatomy of the Human Body*). It is very watery, containing less than 0·6 per cent. of solids. Among the latter are *mucin*, which gives to the saliva its slightly slimy quality, and assists in the swallowing of the food; and *ptyalin*, an enzyme that changes starch into sugar. Saliva is produced in small quantity at all times, but more abundantly when food is in the mouth.

Gastric juice is produced by the innumerable small glands lying in the walls of the stomach. It is watery, colourless, sour, and contains three per cent. of solid matter. Its sourness is due to hydrochloric

(muriatic) acid. It contains two enzymes—viz., *pepsin*, which changes proteid to peptone, and *rennin*, which curdles milk. The glands of the stomach do not act continuously, but are stimulated to activity by the food that has been swallowed.

Intestinal juice is secreted by the glands in the walls of the small intestine. It is not abundant, is a yellowish alkaline fluid, and contains at least two kinds of enzymes, one like the ptyalin of saliva, capable of converting starch into sugar, and the other that changes maltose and other complex sugars into dextrose, a sugar of simpler composition.

Pancreatic juice is manufactured by the pancreas; it resembles saliva in appearance, but contains some thirteen per cent. of solids, among which are sodium carbonate and three powerful enzymes. Of these, *trypsin*, like pepsin, converts proteids into peptones, and, moreover, splits up some of the peptones into other bodies, the reason for which is not quite clear; *amylopsin*, like ptyalin, converts starch into sugar; *steapsin* splits up fat into fatty acid and glycerin. The fatty acid thus produced, with the sodium carbonate present, forms soaps that are capable of emulsifying fats. Hence pancreatic juice may digest all kinds of food stuffs.

Bile is produced by the liver. It is a yellowish or greenish-yellow, somewhat slimy, alkaline fluid, and contains two to three per cent. of solids that are of great variety, but apparently do not include any enzyme. Its secretion goes on continually, six hundred to eight hundred and fifty cubic centimetres (averaging a pint and three quarters) being produced in twenty-four hours. It is stored up in the gall bladder for a time, and passed out into the intestine during the course of digestion. The constituents of bile are largely waste products, thrown off by the living substance throughout the body, removed from the blood by the liver cells, and cast out into the intestine for expulsion. But in addition to its value as an excretion, bile is an important agent in alimentation, aiding greatly, in a manner not yet fully explained, the digestion and absorption of the fats.

Digestive Glands.

The glands that manufacture the digestive fluids consist of chemically active secreting cells that are richly supplied with blood and lymph. They have the power of removing from these fluids some components of the digestive fluids, like water and salts, and other substances from which they manufacture the remaining components. The resulting *secretion* passes on into the alimentary canal. The intestinal glands, the simplest of all, consist each of a little pocket opening into the intestine and with walls of secreting cells (Fig. 3). In the more complex pancreas, liver, and salivary glands the secreting pockets, or alveoli, are greatly branched, tortuous channels uniting into one tube, the duct, which conveys the secretion to the alimentary canal. The glands are among the most active of all the living parts of the body,

and are carefully controlled and regulated by the nervous system. The digestive ferments may readily be extracted from glands that have been removed from the bodies of dead animals, and may be used for the manufacture of artificial digestive fluids. With such fluids the processes of digestion of foods may be carried on under observation in vessels in the laboratory. This has been one of the most fruitful methods of studying the subject. Gland extracts form the basis of many substances used by the physician for the relief and cure of dyspepsia.

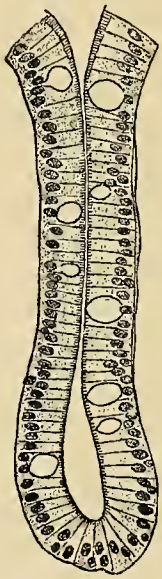

FIG. 3.—GLAND FROM THE HUMAN INTESTINE.

The gland is dilated at its closed end; at the other end it opens into the intestine. Each of the secreting cells of which the wall consists contains a deeply shaded nucleus. The clear spaces represent cells laden with mucus. (Flemming.)

Digestion in the Mouth and Stomach.

Let us now trace in order the events of digestion. Food is put into the mouth, where its presence excites the salivary glands to manufacture and pour out upon it the saliva. The food is, or ought to be, chewed thoroughly, so as finally to divide it and thus to allow the digestive fluids to permeate it readily. The saliva mixes with it, and the chemical changes of digestion begin by the conversion of some of the carbohydrates present into sugar. By muscular action the food is swallowed—that is, is squeezed along through the pharynx and the gullet into the stomach, where it remains for a time varying from a few minutes to a few hours. Waves of contraction pass over the muscular walls; the food, being squeezed here and there, is kept in constant slow motion. The gastric glands are stimulated to activity, and the gastric juice oozing forth mixes with the mass of food and converts it into a half-fluid mass called chyme. The acid of the gastric juice puts a stop to further action of the swallowed saliva. Carbohydrates are hence here unchanged, but the proteids are in great part altered to peptones. At intervals the passageway into the small intestine—the pylorus—opens and allows the chyme to flow out into the duodenum. Thus gradually the stomach completes its work, and transfers its contents to the succeeding part of the alimentary canal.

Digestion in the Small Intestine.

In the small intestine the processes of muscular action, glandular secretion, and digestion are continued. The food is moved about and passed slowly along. The gastric juice ceases to act, intestinal juice and pancreatic juice are added to the mass, and the liver adds its contribution of bile. The carbohydrates that were unaffected by the saliva are changed into sugar.

The proteids that were unaltered by the gastric juice become peptones, and are even in part decomposed into simpler substances. The fats are for the first time affected, being in small part decomposed into fatty acid and glycerin, in greater part divided mechanically into fine droplets. This emulsification is assisted by the soaps that are formed by a union of the fatty acids and the alkalies present in the digestive fluids. Thus all classes of food stuffs are attacked in the small intestine; no other part of the whole canal forms so active a digestive laboratory as this part. Besides the changes already spoken of, due chiefly to the enzymes, the object of which is to make ready the nutriment for entrance into and use by the protoplasm, fermentative changes of the digested products take place of a destructive character, and due apparently to the agency of living microbes that are always present in the intestine. The significance of this apparent destruction of nutritive substance is not understood. The bacteria are not disease-producing germs; on the contrary, they may possibly be of considerable value to the body, but the rôle that they play needs investigation. Absorption of the digested food into the blood and lymph is most active in the walls of the small intestine, and by the time the semifluid mass has reached the ileo-cæcal valve it is robbed largely of its nutritious components.

Digestion in the Large Intestine.

In the large intestine no new physiological features are added. Feeble digestion, fairly active absorption of digestive products and of water, and marked fermentation by bacteria, are the main events; and the undigested and the indigestible substances are passed on into the rectum for expulsion from the body. The large intestine appears to be physiologically more important in herbivorous animals, like cows and sheep, where, in accordance with the enormous quantity of food, it is relatively large. It was doubtless larger and more important in the ancestors of the human race. But in man it appears to be undergoing degeneration, as is shown especially in the part known as the vermiform appendix. This appendage, probably valuable in the digestive work of the ancestors of man, seems to be devoid of marked function in man at the present time, and is especially prone to inflammatory processes set up by the presence within it of irritating substances brought there by the food. It would seem a blessing if evolution could hasten the disappearance of this apparently useless structure.

Vermiform Appendix.

Absorption.

A word now as to the absorption of the digested food stuffs, and the outline of the story of alimentation will be completed. Within the alimentary canal the food is no more a part of the body than if it were upon the outer surface. As has been insisted, digestion within the alimentary canal is merely a preparation of the food for entrance into the actual living substance. The cells that

line the canal are nourished by absorbing food directly from the mass that lies in contact with them. More distant cells require nutriment to be brought to them, and this is one important office of the blood and lymph with which the walls of the alimentary canal are so saturated. Thin-walled blood capillaries and lymph capillaries abound there, and during and after digestion the dissolved food stuffs make their way into them. Absorption takes place very slightly, if at all, in the stomach; it is at its greatest height in the small intestine, and it is active even throughout the large intestine. The method of absorption is not wholly clear. Probably physical processes play a leading part; but it is a question whether the living cells that line the intestine, and through which the food must pass on its way to the capillaries, may not in some manner engage actively in the process. Sugar and fats pass through them unchanged, peptone is mysteriously altered chemically in its passage. This altered peptone, the sugar, and the greater part of the salts and the water go directly into the blood. Fat goes into the lymph and, by way of the lymphatic vessels and the thoracic duct, finally into the blood system. Thus all nutriment that is not used by the living substance in the wall of the alimentary canal finds its way sooner or later to the blood, the great carrier and distributer of matter and energy. Our next section deals with this circulating mechanism.

Section II.

CIRCULATION.

In an organism that consists of one cell or a few cells, food, when once digested, permeates all parts readily. In larger organisms this is impossible, and hence special mechanisms must exist for the transfer of nutriment from the organs of digestion to the more distant parts. In the growth of all except the simplest animals such a mechanism, some sort of a distributing system, is developed. It is simple and crude in its beginnings, and in the lower organisms remains always simple and crude. It becomes more complex and perfected as the animal's size increases and his structure becomes more complex, until in the completed circulatory system of the highest animals and man we have an apparatus that is wonderfully adapted to perform its needed work, and responsive in a high degree to the demands of the other physiological systems. The transfer of nutriment is not the only important function of the organs of circulation. Of equal value are the transfer of oxygen without which the living substance can not act, and the removal of waste products from the tissues to the organs of excretion. Furthermore, it must be borne in mind that the

Circulation in General.

food contains not only material for the manufacture of new protoplasm, but also in a latent form all the energy of which the body makes use; hence the circulation is the medium for the transference of energy from one part of the body to another. Finally, as we shall discuss later, the same system acts to keep the temperature of the various portions of the body uniform. A review of the circulation comprises a study of the two fluids which serve as carriers of the oxygen, the food, the energy, and the wastes—viz., the *blood* and the *lymph*, and a study of the organic mechanisms by which they are made to move.

Blood and its Constituents.

Blood may be regarded as a tissue consisting of a lifeless, slightly yellowish liquid, the *plasma*, and living cells, the *corpuscles*. The plasma contains in solution the food and the waste matters, hence its composition is complex. Besides water, it contains eight to nine per cent. of solid substances, comprising among other bodies proteids, sugar, fats, and salts. Some of these constituents originate in the digested food stuffs. It contains also a gas, carbonic acid.

The corpuscles are of three kinds, the red, the white or colourless, and the blood-plates, which are also colourless (Fig. 4). The red corpuscles are most numerous, it being estimated that in one cubic millimetre of blood ($\frac{1}{15625}$ of a cubic inch) there exist five millions in man and about a half million less in woman. The number in the whole body is inconceivably great. They are biconcave round disks about $\frac{1}{3200}$ of an inch in diameter, and consist of a bit of protoplasm coloured by a reddish pigment called *hæmoglobin*. Hæmoglobin gives to the blood its colour, and is one of its most important constituents by reason of having a special attraction for oxygen. When the blood in its course passes through the lungs, its hæmoglobin absorbs oxygen from the air that has been breathed in, and holds it until the gas

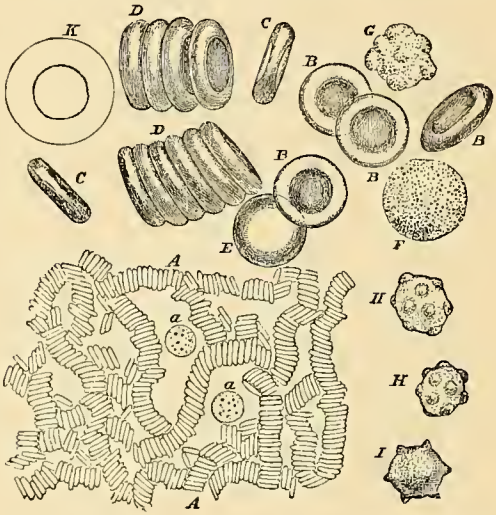

FIG. 4.—RED AND WHITE CORPUSCLES OF THE BLOOD, MAGNIFIED.

A, moderately magnified: the red corpuscles are seen lying in rouleaux; at *a* and *a* are seen two white corpuscles; *B*, red corpuscles much more highly magnified, seen in face; *C*, ditto, seen in profile; *D*, ditto, in rouleaux, rather more highly magnified; *E*, a red corpuscle swollen into a sphere by imbibition of water; *F*, a white corpuscle magnified same as *B*; *G*, ditto, throwing out some blunt processes; *K*, ditto, treated with acetic acid, and showing nucleus, magnified same as *D*; *H*, red corpuscles puckered or crenate all over; *I*, ditto at the edge only. (Huxley.)

is required by the tissues. The task of the red corpuscles is hence that of carriers of oxygen. In cases of murder or other crimes, where a stain is suspected to be caused by blood, an examination with the microscope, by revealing the red corpuscles, will decide the question. Even if the corpuscles have been destroyed, the presence of hæmoglobin can easily be detected by proper chemical methods. Human red blood-corpuscles may be distinguished readily from those of fishes, frogs, reptiles, or birds, but not conclusively from those of higher animals except the camel. Human hæmoglobin is not distinguishable from that of other animals.

The white corpuscles are colourless cells of somewhat irregular shape, roughly spherical, about $\frac{1}{2400}$ of an inch in diameter. They are much fewer in number than the red corpuscles. They have the peculiar power of creeping about through the walls of the blood capillaries, and in among the cells of the tissues throughout the body. Their specific work is not fully known. It has been thought that they may be of special benefit to the body, when attacked by germ diseases, by absorbing the bacterial germs into their substance and destroying them.

The blood-plates were discovered only recently. They are minute, colourless, spherical, or elliptical bodies, that go to pieces very easily. This happens especially when blood is shed, in which case they seem to aid in the clotting of the blood. Their office within the body is unknown.

The quantity of blood in a healthy man of one hundred and fifty pounds is about five and a half quarts.

When blood is shed it has the peculiar property of clotting or thickening into a jelly-like mass. The special value of this property lies in its use in stopping the loss of blood from wounds; if it were not for this, the slightest injury to the skin might result in bleeding to death. Clotting consists in the formation from *fibrinogen*, one of the proteids existing in the plasma, of an insoluble substance called *fibrin*. Fibrin exists in the clot in the form of fine whitish threads that extend in all directions and form a spongy network. This holds in its meshes the corpuscles, and the whole forms an effectual plug for the wound. By the spontaneous shrinking of the fibrin threads a yellowish fluid, that is really plasma minus the fibrin and is called *serum*, is squeezed out.

Lymph.

Lymph is a colourless fluid, occurring partly in the lymphatic vessels and partly in the spaces between the cells of the tissues. It thus comes more closely into contact with the living protoplasm than the blood, the latter never leaving its vessels. It is much like blood in composition, but lacks the red corpuscles and the blood-plates. After a meal of fat the lymph in the lymphatics of the intestine is loaded with fat droplets, and is pure white in colour like milk,

the whiteness of which is due to the contained droplets of butter. Such lymph is called *chyle*, and the lymphatics in that region are known as *lacteals*.

Circulation of the Blood.

The blood is moved through the blood-vessels by the contractions of the heart. The motion was thought formerly to be a sluggish oozing from the heart to the tissues. But in 1628 it was shown by the Englishman, William Harvey, physician to Charles I., that every particle of blood makes a complete circuit of the blood-vessels, and returns ultimately to its place of starting; that the blood moves, so to speak, in a circle, and since Harvey's time the movement has been spoken of as the circulation of the blood. The circulatory organs of the blood system consist of the heart, the arteries, the capillaries, and the veins. The heart pumps the blood into the main arteries; along these the liquid courses toward the tissues, passing into smaller and smaller arteries, and finally into the minute capillaries; in the capillaries it permeates the tissues and courses among the living cells; from the capillaries it passes into the small veins; these unite into larger and larger vessels, and finally, by a few large venous trunks, the blood returns to the heart again. For the structure and arrangement of the circulatory organs, and for the general plan of the circulation, the reader is referred to the article on *The Anatomy of the Human Body*, Sections IV and V, and to the accompanying figure (Fig. 5). In order to make the complete circuit of the circulatory organs, any particle of blood must traverse two sets of arteries, capillaries, and veins, and all four chambers of the heart. The path from the left ventricle through the blood-vessels of

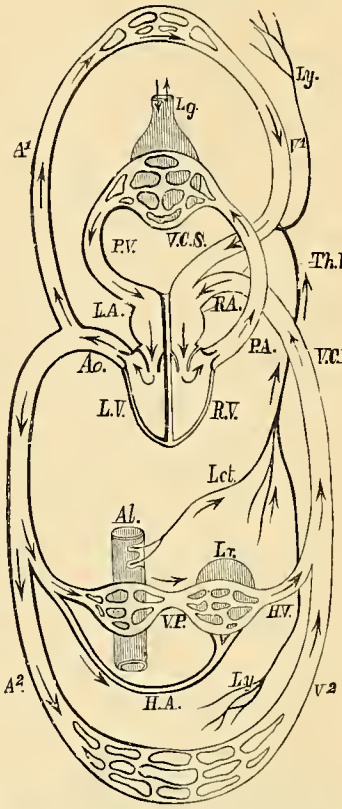

FIG. 5.—DIAGRAM OF THE HEART AND VESSELS, WITH THE COURSE OF THE CIRCULATION, VIEWED FROM BEHIND, SO THAT THE PROPER LEFT OF THE OBSERVER CORRESPONDS WITH THE LEFT SIDE OF THE HEART IN THE DIAGRAM.

L.A., left auricle; *L.V.*, left ventricle; *Ao.*, aorta; A^1, arteries to the upper part of the body; A^2, arteries to the lower part of the body; *H.A.*, hepatic artery, which supplies the liver with part of its blood; V^1, veins of the upper part of the body; V^2, veins of the lower part of the body; *V.P.*, vena portæ; *H.V.*, hepatic vein; *V.C.I.*, inferior vena cava; *V.C.S.*, superior vena cava; *R.A.*, right auricle; *R.V.*, right ventricle; *P.A.*, pulmonary artery; *Lg.*, lung; *P.V.*, pulmonary vein; *Lct.*, lacteals; *Ly.*, lymphatics; *Th. D.*, thoracic duct; *Al.*, alimentary canal; *Lr.*, liver. The arrows indicate the course of the blood, lymph, and chyle. The vessels which contain arterial blood have dark contours, while those which carry venous blood have light contours. (Huxley.)

the body, except the lungs and to the right auricle, is called the "greater" or "systemic" circulation; the path from the right ventricle through the vessels of the lungs to the left auricle is called the "lesser" or "pulmonary" circulation. The significance of this double circulation lies in the facts that in the capillaries of the tissues of the body the blood delivers up food and oxygen to the cells and receives waste products from them; and that in those of the lungs the gaseous waste, carbonic acid, is thrown off into the air to be expelled in the breath, while the blood is in return charged highly with oxygen. The left side of the heart hence carries purified blood charged with oxygen, the right side impure blood charged with carbonic acid and other waste matters. These latter wastes are removed from the blood capillaries and from the body by the kidneys and the skin. As has been already said, the food is received into the circulation partly in the capillaries of the intestinal wall and partly directly into the veins from the lymphatic ducts.

Thus all exchange between blood and living protoplasm takes place through the capillary walls. In harmony with this function these walls consist of a thin membrane made up of flat cells joining one another edge to edge, and allowing a ready diffusion of the liquid blood plasma (Fig. 6). As the capillaries pass on the one hand into the arteries, and on the other into the veins, the walls become thickened by the addition of a layer of muscle outside of the lining membrane and one of connective tissue outside of the muscle. Both these layers are thicker in the arteries than in the veins, and in the former the connective tissue is highly elastic. Thus the arteries are thick-walled, active, elastic structures, capable of altering their calibre greatly, and thus regulating the amount of blood going to the capillaries. If a particular capillary area requires a large quantity of blood, the muscles of the adjoining arteries relax and the arteries dilate; if less blood is desired, the muscles contract and constrict the supplying arteries. The veins are thinner walled and passive, and are in brief drainage-tubes for the capillaries and the tissues. The arteries are thus physiologically more interesting than the veins. If an artery be cut, the thickness and stiffness of its walls cause it to stand wide open, and the blood gushes freely out; if a vein be severed, its walls collapse, and the blood hindered in its flow may clot more readily and less loss may result. Hence wounding an artery is usually a much more serious and dangerous affair than wounding a vein. In this

Structure and Function of Vessels.

FIG. 6.—CAPILLARY CIRCULATION IN THE WEB OF THE FROG'S FOOT.

connection it is interesting to recall the fact that as a rule the arteries lie much farther from the surface of the body than the veins—a most valuable adaptation of Nature. Exceptions to the rule are the radial artery which comes near to the surface at the wrist, the artery at the temple, and a few others. But the veins have one mechanism peculiar to themselves—that is, the curious and very numerous little pouch-like valves that project into the tubes and prevent any back-flow of blood toward the capillaries when any influence, such as pressure on the skin, tends to hinder the venous flow (Fig. 7). Even if the veins are thin-walled and inactive, their valves do not allow their circulation to be seriously interfered with by extraneous pressure.

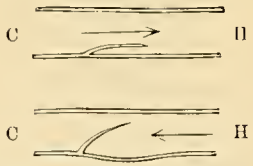

Fig. 7.—Diagrammatic section of veins with valves.

In the upper figure the blood is supposed to be flowing in the normal direction from C (capillary) to H (heart); in the lower figure pressure upon the surface of the vein has temporarily forced the blood backward and closed the valve. (Huxley.)

Physiological Anatomy of the Heart.

The heart in its embryonic origin is a simple tubular blood-vessel, and in some of the lower and simpler organisms, such as the worms and the tunicates, it retains its tubular character throughout life. But in the growth of all higher animals, including man, its simple form is early modified by its being curved upon itself, by partitions forming within its cavity, by valves appearing at certain places, and by its walls becoming greatly thickened by muscular tissue. It thus becomes a complicated muscular pump, a part of the circulatory system specially modified by Nature for the purpose of propelling the blood around its circuit. For the details of the anatomy of the heart the reader is referred to the article on *The Anatomy of the Human Body*, Fig. 27. It will be remembered that the organ is four-chambered, comprising two thin-walled upper chambers, the auricles, and two thick-walled lower ones, the ventricles. A partition extends the whole length of the heart, separating the auricle and ventricle of the right side from those of the left side. Each auricle receives blood from veins, and opens below into the corresponding ventricle. The pulmonary veins, bringing blood from the lungs, join the left auricle; the two great veins that bring blood from the rest of the body, the superior and the inferior venæ cavæ, enter the right auricle. Each ventricle opens into an artery—the right one into the pulmonary artery which conveys blood to the lungs, the left one into the aorta, which is the largest artery of all, and supplies with blood all parts of the body except the lungs. The course of the blood stream has been mentioned already, and may be seen readily from the accompanying diagram (Fig. 5). The direction of the flow is determined by the valves. Of these there are two kinds: the auriculo-ventricular valves at the opening of each auricle into

its ventricle, and the semilunar valves at the origin of both the aorta and the pulmonary artery. The former allow the blood to pass from the auricles to the ventricles, but not to return; the latter allow it to flow from the ventricles into the arteries, but not to return.

Beat of the Heart.

The movement of the blood is caused by contractions of the muscle in the walls of the heart, the muscle being so arranged that each contraction diminishes the size of the heart chambers, and the blood is thereby squeezed upon and forced out. The contractions are commonly called "beats," and are performed rhythmically. In the newborn child the heart beats at the rate of one hundred and thirty to one hundred and forty times in the minute. During childhood and youth the rate gradually diminishes, and throughout the greater part of adult life remains at about seventy-two. The events of each beat in brief and in order are as follows: The gradual flowing of blood from the veins into the auricles and from these into the ventricles; the sudden short contraction of both auricles for the purpose of overfilling the ventricles and causing the auriculo-ventricular valves to rise upward and shut off communication between auricles and ventricles; sudden contraction of both ventricles by which the contained blood is put under tension, the semilunar valves are pressed open, and the blood is shot out into the aorta and the pulmonary artery with sufficient force to drive it through the arteries, the capillaries, and the veins back again to the opposite auricle. Immediately after contraction the semilunar valves close, each heart chamber relaxes and fills with blood from the veins, its muscles rest, and, in a fraction of a second, have recovered energy for a second beat. This follows, and a third, and a fourth, and so the cycle is repeated with alternations of activity and of rest, of systole and diastole, throughout the life of the individual, the order of events never changing unless some form of "heart disease" interferes with the working of this most beautiful of all animal mechanisms.

Heart Sounds.

It is apparent that the course of the blood along the arteries is intermittent, wave after wave following one another at intervals of less than a second. Each wave or *pulse* is, of course, the direct result of the ventricular beat, and hence the physician regards the pulse as one of the best indications available to him of the condition of the heart. The practised ear may infer much also from the *heart sounds*, which may be heard readily by laying the ear on the chest wall over the heart. These are two—a longer, faint, low-pitched tone, due to the contraction of the ventricles, and immediately followed by a short, higher-pitched, abrupt one, caused by the closing of the semilunar valves. If the parts are altered by disease the sounds are altered.

The smaller arteries and the capillaries are excessively fine tubes, the diameter of some of the latter being even as small as $\frac{1}{3200}$ of an inch, the

diameter of a red corpuscle. The result is that the resistance to the flow in them is enormous, and the blood tends constantly to accumulate in the arteries. The walls of the arteries are thereby put under great tension, the pressure of the blood within them is great, and their elasticity is brought into play. The result of this combined capillary resistance and arterial elasticity is that by the time the blood has reached the smallest vessels the pulse has disappeared, and the flow is continuous in both the capillaries and the veins. Many more details might be given of the events of the blood movement were there space, for even from the very earliest times, and especially since, in 1628, Harvey gave the right interpretation of the leading facts, and since Malpighi, in 1661, first saw with his microscope the exquisite and wonderful picture of the blood corpuscles picking their way through the tortuous capillary channels in the wall of the frog's lung, the circulation has been a favourite study with all schools of physiologists. Many of the once mysterious facts have been shown to be explicable by the common laws of mechanics. Although the heart is a living pump and the vessels living tubes, the circulatory system presents many of the same problems as are presented by any system of closed elastic pipes through which liquid is pumped. Other problems, however, defy the attacks of the mechanical, physical, or chemical physiologists, and prove that the experimental laboratories have still much to do.

Of these latter problems, which for lack of a better word may be called "vital," two may here be mentioned—viz., the causation of the heart beat, and the regulation and co-ordination of the various parts of the circulatory apparatus. The beat itself is an excellent example of what physiologists are wont to call spontaneous actions—*i. e.*, actions which originate within the tissue itself, and do not require a stimulus from without to set the tissue going. By this is not meant a causeless action; every action has one or more causes, but the causes of spontaneous actions are to be sought within the acting part itself. The beat of the heart is a spontaneous action. It has been abundantly proved in lower animals and even in the higher quadrupeds that the heart when removed from the body will continue to beat even for hours if it be supplied with proper nourishment and warmth, and this fact no doubt would apply to the human heart, were it possible to test it. The impulse to the beat is then to be sought in the heart itself, but in what tissue? The heart contains much nervous tissue, consisting of nerve cells, which send off filaments, the nerve fibres, to the cardiac muscle cells. In general it may be said that nerve tissue is more inclined to spontaneity than muscle tissue. Within the heart, then, does the impulse to beat originate in the muscle cells that do the contracting, or does it originate in the nerve cells and pass from them along the nerve fibres to the muscle cells? The question is a fundamental one for physi-

Cause of Heart Beat.

ologists, and its answer would be a valuable contribution to the interesting subject of the evolution of muscular and nervous function. In the lower and simpler animals spontaneity is a characteristic of almost all kinds of cells and tissues; as the evolution of the higher animals has gone on, gradually the tissues have become less spontaneous in their actions and more dependent upon impulses coming to them from the nervous system, until, in the higher animals, the work of the body is largely performed as the result of nervous action. In accordance with this the nervous system retains its primitive spontaneity in a high degree. In the hearts of invertebrates, as the snail, and perhaps some low vertebrates, as the frog and the turtle, the impulse to beat appears to originate in the cardiac muscle cells; in the higher vertebrates it is yet unsettled whether it is nervous or muscular in origin. Why the heart tissue acts rhythmically is another inviting subject, not yet understood, into which we have here not time to go.

Nervous Control of the Heart.

Although, as we have seen, the heart does not need any impulse from outside to enable it to continue its contractions and do its work, yet its contractions are always regulated and controlled by nervous impulses coming from the brain. From the part of the brain lying at its base and called the medulla oblongata, situated just within the skull at the back of the neck, nervous impulses go out to the heart along certain nerves. Along the two vagus nerves (see *The Anatomy of the Human Body*) may go impulses which cause the heart to beat more slowly or more weakly than before. These come from the so-called *cardio-inhibitory centre* in the medulla, and if sufficiently intense they may cause the heart actually to stop beating. Along the sympathetic nerves may go impulses that cause the heart to beat more rapidly or more strongly than before; these come also from an *augmentor* or *accelerator centre* situated probably in the medulla. These two centres are thus antagonistic in their action on the heart. They are in nervous connection with other parts of the central nervous system and thence with all parts of the body, and through them the heart is delicately controlled constantly as to rate and force of beat, so that its work is adapted to the needs of the body at every moment. As examples of extreme activity of these nerve centres may be mentioned, first, the slowing or actual stopping of the heart by a sudden heavy blow in the pit of the stomach, or by a sudden shock caused by a piece of bad news. In both cases the cardio-inhibitory centre is stimulated to activity; in the former through nerves going up from the stomach to the medulla, in the latter through nerve fibres within the brain itself, extending down from the consciously acting brain centres above that have taken cognizance of the bad news. In both cases the result, as stated, is slowing or stopping of the heart; the fainting that usually accompanies is a secondary result, due

to the fact that the weakened heart fails to pump the necessary blood to the consciously acting brain, and unconsciousness results. Second, the very rapid fluttering of the heart accompanying mental excitement is no doubt due to excessive stimulation of the accelerator centre, and thus of the heart, by impulses coming likewise down from the higher brain cells. A little consideration will show that slowing of the heart may result theoretically from activity of inhibitory nerves or from the cessation of activity of accelerator nerves; and the like applies *vice versa* to acceleration. Physiology has not yet unravelled all the mysteries of the interactions of these two antagonistic nerve influences. It may be mentioned here incidentally that the rapid pulse present in fever is probably due to the hot blood stimulating directly the heart muscle to excessive activity.

Nervous Control of the Arteries.

The blood supply to the various parts of the body must needs vary constantly, according as any part requires more or less blood at one time than at another. A tissue in action needs more blood than the same tissue at rest, because it needs more food and more oxygen, and because the injurious waste products of its activity must be removed. When the brain thinks, it needs more blood than when it sleeps; when the digestive glands are secreting, they must have blood in abundance; when a man works with his muscles, they demand an extra allowance of blood. Obviously, mere alteration of the heart beat affects the general blood supply, but affects all parts equally. Nature has, however, evolved an efficient method of varying the supply according to the needs of the individual parts. The method consists in varying the calibre of the artery that brings blood to each part. Constriction or narrowing of an artery causes the quantity of blood to be diminished; dilatation or widening causes it to be increased. The calibre of the arteries, like the action of the heart, is regulated through special nerves by a particular part of the brain. Such nerves are called *vaso-motor*, from the fact that they supply the muscles or motor part of the arterial walls. The vaso-motor nerves are of two kinds, quite analogous in their functions to the two kinds of cardiac nerves: the *vaso-constrictors* have the power of causing the muscular coat of the arterial walls to contract, and thus a constriction of the artery results (analogous to augmentation of the heart beat); the *vaso-dilators* cause relaxation of the arterial muscle and hence a dilation of the vessel (analogous to cardiac inhibition). These nerves go to the arteries from a *vaso-motor centre* in the medulla oblongata. This part of the brain, like the cardio-inhibitory centre near which it lies, is affected by influences coming from all parts of the body, and its actions are determined by the nature of these influences. It is capable of controlling the calibre of each artery, and thus of constricting or dilating small or large vascular areas. Like the case of cardiac augmentation or inhibition, arterial constriction and dilation may

result theoretically not only from direct constricting and dilating impulses, but each may also follow from the cessation of impulses leading to the opposite activity. Hence the mutual interactions of these two influences become excessively complicated and present a problem not yet wholly solved. As examples of vaso-motor actions may be mentioned the two cases of blushing and becoming pale, due in the one case to arterial dilation, and in the other to arterial constriction, of the small arteries in the skin of the face. The exciting cause in each case is an unusual thought or emotion originating in the brain and causing nervous impulses to pass down to the vaso-motor centre in the medulla, in the one case decreasing its activity, in the other increasing it. Just why one emotion causes blushing and another paleness is not clear. As might have been expected, of all the blood-vessels the arteries alone are known to be markedly controlled by nerves. The vaso-motor nervous apparatus and the cardiac nervous apparatus are connected within the medulla and work in harmony with each other. Together they form a mechanism of remarkable adaptation and refinement.

The Lymphatic System.

As will be seen from the article on *Anatomy*, the lymphatic system is comparable in a general way with the capillary and the venous systems—*i. e.*, it consists of capillaries uniting to form larger vessels, and these in turn unite into two large trunks. The capillaries take their origin in irregular spaces among the tissues. (See *The Anatomy of the Human Body*, Fig. 36.) The lymphatics receive openings from such large cavities as those of the abdomen, of the chest, and of the pericardium. At intervals they open into the irregular cavities within the lymphatic glands. And finally the two trunks, the thoracic duct and the smaller right lymphatic duct, open into the great veins at the root of the neck. The walls of the lymphatics are not unlike those of the capillaries and veins in structure, but they are excessively thin. Valves, like the venous valves, are very abundant in the vessels. The lymph not only fills the lymphatic organs, but exists also in all cell spaces and interstices of the tissues, and thus bathes the living cells much more intimately than does the blood. The lymph may be regarded as a carrier between the blood and the living cells, all food and all waste matters probably having to pass through it in their passage between the protoplasm and the blood-circulating system. The plasma of the lymph is blood plasma that has escaped through the thin walls of the blood capillaries into the spaces in the surrounding tissues; the corpuscles of lymph are in part escaped white blood-corpuscles and in part new cells that are formed by division of cells within the lymphatic glands. The lymph thus originating constantly in the tissues passes into the lymphatic capillaries, flows constantly along the vessels, and empties itself into the veins. In all vertebrates below the mammals a varying number of lymph hearts

exist—simple muscular sacs attached to various lymphatic vessels, and capable, like the blood heart, of rhythmic contractions. No such organs are known to exist in man and other mammals. The movement of the lymph is due to several agencies, such as pressure exerted upon the vessels by the muscular movements of the body, the existence of a lower pressure in the veins than in the lymph-vessels themselves, and possibly rhythmic contraction of the walls of the vessels. The numerous valves prevent any possibility of a flow in the wrong direction. Thus both structurally and functionally the lymphatic system is a much less highly specialized apparatus than the blood system. The latter, with its efficient means of propulsion and its elaborate nervous mechanism for regulating speed and distribution, is, like the railway system, an efficient and rapid carrier. But, just as between the factory and the railway, or between the latter and the consumer, the drayman's cart is indispensable, so in the body, between the place of digestion and the blood, or between the blood and the living cells, the lymph finds its tasks. The lymphatic system and the blood system together form a most efficient distributing and collecting mechanism.

We have thus traced the food from outside the body to the living cells. Without oxygen the cells can not utilize it. We have now to consider the source of the oxygen.

Section III.

RESPIRATION.

The lungs and other respiratory organs have a twofold function—that of bringing to the blood the oxygen that is as essential to life as is the food, and that of removing from the blood and from the body water and certain waste and poisonous products, mainly carbonic acid. The great importance of the whole process is indicated by the facts that the respiratory organs occupy so large a space in the body; that the right ventricle of the heart has as its sole function that of supplying blood to them; and that during the lifetime of the individual all the blood in the body must pass through them once in every twenty or twenty-five seconds—the time occupied by the blood in making the complete circuit of the body. To insure rapid and efficient exchange of the two gases, oxygen and carbonic acid, the blood and the air must be brought into as close proximity to each other as possible; hence we find the lung to consist mainly of innumerable

Respiration in General.

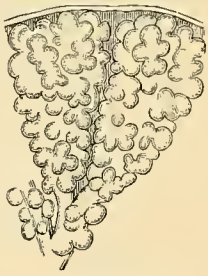

Fig. 8.—Termination of two bronchial tubes in enlargement beset with air sacs. (Huxley.)

small *air sacs* (Fig. 8) with excessively thin walls containing a little elastic connective tissue lined by a layer of flat, thin epithelium cells, and loaded with a rich network of fine blood capillaries. The air sacs are continuous with the bronchial tubes, and communicate through the trachea with the outside air (Fig. 9). The blood is separated from the air by the thin epithelial membrane consisting of capillary wall and wall of air sac

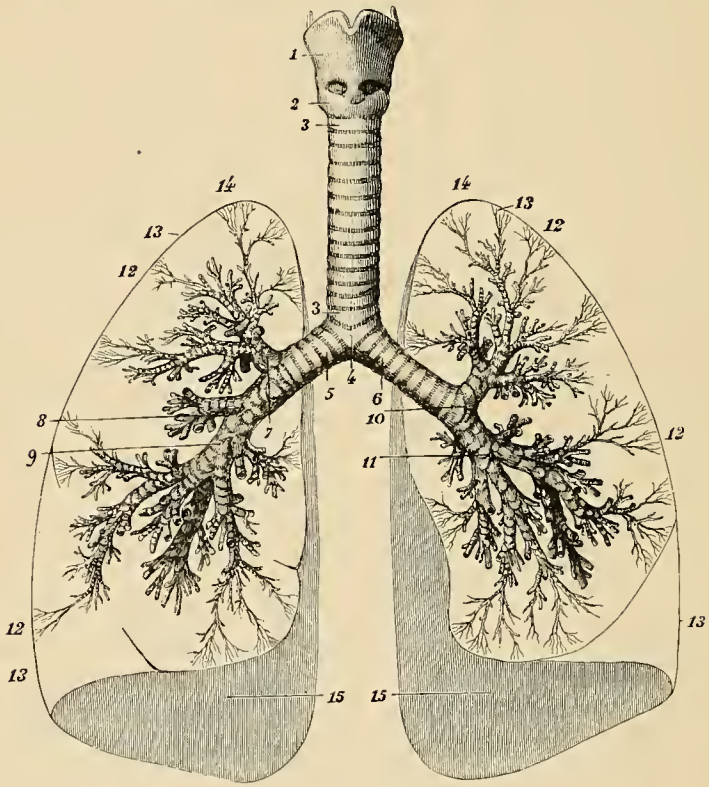

FIG. 9.—TRACHEA AND LUNGS, DISSECTED TO SHOW BRONCHIAL TUBES.
1, 2, larynx; 3, 4, trachea; 5, 6, bronchi; 7, 8, 9, 10, 11, bronchial tubes, a few only being shown as far as their terminations; 12, 13, 14, 15, surface of lungs. (Sappey.)

(Fig. 10). Thus the conditions needed for ready diffusion are present. The total amount of air surface exposed in the lungs appears to be more than two hundred square yards, and the amount of capillary surface more than a hundred and fifty square yards. The blood is renewed constantly by the circulation; the air is exchanged constantly by the respiratory movements; and the result of the interchange between the two media through the intervening membranous wall is that, while impure blood and pure air have entered the lungs by their respective channels, pure blood and impure air go out from them.

The respiratory movements consist of those of *inspiration* and *expiration*. In both of these acts the lungs are passive organs. The activity resides in the muscles of the chest walls. It will be remembered that the lungs are inclosed within an air-tight cavity, the thorax or chest, which is bordered at the top and sides by the ribs and the intercostal muscles, and below by the dome-like muscular partition, the diaphragm. Contraction of the external intercostal muscles raises the ribs, pushes the sternum or breast bone outward, and enlarges the whole chest cavity. Enlargement of the chest may be brought about also by contracting and thereby lowering the diaphragm. The inspiratory act consists in enlarging the chest by simultaneous contractions of both these muscles with the assistance of other muscles of the thoracic walls. The walls of the lungs follow passively the movements of the walls of the air-tight and air-empty chest, and the capacity of the lungs is correspondingly increased; to balance this the air rushes in passively through the nostrils or mouth, pharynx, trachea, and bronchial tubes. Thus we do not breathe air in, as our sensations might mislead us to believe, through any action exerted upon the air by our nostrils or lungs. When we wish air we contract our diaphragm and the muscles of our ribs, and air must come in. Both sexes use both muscles, but in women respiration by movement of the ribs, or "costal" respiration, predominates; in men the "diaphragmatic" or "abdominal" method is more prominent. It has been greatly discussed and is still undecided whether this is a fundamental sexual difference associated with the function of childbearing in woman, or whether it is due to the tightness of woman's dress about the abdominal region and the prevention of the free action of the diaphragm. The expiratory act is the reverse of that of inspiration: the muscles cease their contraction, the ribs and the diaphragm return to their former positions, the tension on the lungs is removed; by their elasticity the lungs return to their former size, and the excess of air is squeezed out. Only when the breathing becomes laboured, as in active exercise, or when from any unusual cause there is danger of suffocation, does expiration become a muscular act, carried on by various muscles attached to the walls of the chest and the abdomen. Respiration is a rhythmic, ordinarily unconscious action, repeated on an average seventeen to eighteen times in the minute in the adult, but more rapidly in children.

Respiratory Movements.

Sexual Differences in Respiration.

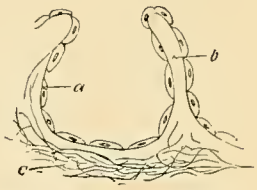

FIG. 10.—DIAGRAMMATIC VIEW OF AN AIR SAC.

a, lies within sac and points to epithelium lining wall; *b*, partition between two adjacent sacs, in which run capillaries; *c*, elastic connective tissue. (Huxley.)

At each respiration about thirty cubic inches of air ("tidal air") passes into and out of the air passages and mixes with the "stationary air"

(about one hundred and eighty cubic inches) that the lungs contain at all times. The actual exchange of gases between the tidal and the stationary air takes place by diffusion. The result of the exchange is that the expired air is saturated with moisture, is warmer than the inspired air, and contains about five per cent. less oxygen, about four per cent. more carbonic acid, and a minute quantity of obscure deleterious substances of unknown nature, to which the odour of the breath is due.

Respiratory Changes in Air.

The respiratory muscles are not, like the heart, automatic; they need to be stimulated for each contraction; and a particular part of the brain has been specialized to originate and send out to them the necessary impulses. This is the so-called *respiratory centre* or "vital spot," and it lies in the medulla oblongata at the base of the brain. Its presence there makes this portion of the brain seem so important, for any serious injury to the centre stops respiration and thus puts an end to life. Hence the fatality in breaking the neck. The nerve cells composing the centre are put into activity, apparently, by the impure venous blood circulating about them; they inaugurate an inspiratory impulse and discharge it along the intercostal and the phrenic nerves to the respiratory muscles, causing the latter to act. Exactly how the regular alternation of inspiration and expiration comes about is not wholly explained, but the centre seems to be regulated in its activity by nerve impulses coming from the lungs. It is, in fact, one of the most sensitive parts of the nervous system, all modifications of breathing that take place in laughing, crying, coughing, sneezing, hiccoughing, sighing, "catching one's breath," muscular exercise, talking, singing, stepping into a cold bath, etc., being due to influences altering the regular working of the respiratory centre. The peculiar facial expressions and characteristic vocal sounds that accompany laughing and crying are to be distinguished from the modified breathing. It is not easy to conceive how and why these peculiarities of facial expression, sounds and breathing, which are evidences of pleasure or of grief, and the beginnings of which seem to be found in animals lower than man, have been developed.

Nervous Control of Respiration.

The changes that the blood undergoes in its passage through the lungs are in harmony with and are no less striking than those of the air. The blood loses to the air contained in the air sacs of the lungs six to eight per cent. of carbonic acid, and gains from it eight to twelve per cent. of oxygen; it comes to the lungs purplish in colour; it leaves them bright scarlet. The gaseous exchange between air and blood takes place chiefly by the physical process of osmosis through the thin cellular membrane separating them; but the cells of this membrane may possibly act like gland cells to "secrete" the two gases.

Respiratory Changes in the Blood.

Colour of the Blood.

The change of colour of the blood is interesting. It will be remembered that the red colour is due to the colour of the hæmoglobin that exists in the red corpuscles, and also that the red corpuscles are the carriers of oxygen. The hæmoglobin exists in the body in two forms—in venous or impure blood, largely as *reduced hæmoglobin*, and in arterial or pure blood, as *oxyhæmoglobin*. Reduced hæmoglobin contains little oxygen and is purplish in colour; oxyhæmoglobin contains much oxygen and is scarlet in colour. The hæmoglobin that is brought to the lungs is in the reduced form; it greedily seizes upon the oxygen that is absorbed through the capillary walls; it becomes oxidized; and the colour of the hæmoglobin, the red corpuscles, and the blood changes accordingly to the bright-red tint.

Respiration by the Skin.

Besides the pulmonary respiration, slight exchange of oxygen and carbonic acid takes place directly through the skin. This method of breathing is of great importance to some of the lower animals, such as frogs and worms, but in man it is very subordinate.

Internal Respiration.

The specific respiratory organs work for the body as a whole. In the broad sense, however, all living cells are respiratory, since they take in oxygen and give out carbonic acid. Such a process is often spoken of as *internal* or *tissue* respiration. The lungs and the skin mediate between the air and the blood and lymph. The blood and the lymph are carriers between the respiratory organs and the living tissues. Charged with oxygen in the lungs, the blood is sent throughout the body, and everywhere in the capillaries it courses among living cells that require oxygen. The oxyhæmoglobin is robbed of its contained gas and becomes reduced, while the blood changes to a purplish colour. The cells, on the other hand, are constantly giving off carbonic acid, and this by diffusion passes readily into the blood. The lymph has in tissue respiration a function analogous to that which it has in tissue nourishment: it is the mediator between the blood and the living cells. Hence the result of tissue respiration as regards the blood is exactly the reverse of that of pulmonary respiration. The respiratory relations of the pulmonary and the systemic circulatory systems hence appear in a new and striking light. The former deals with the respiratory needs of the body as a whole, the latter with the respiratory needs of the living particles of which the body is composed.

In considering respiration we have unavoidably touched upon the excretion of one waste product—carbonic acid. The other wastes may now be studied.

Section IV.

EXCRETION.

Leaving for the present the consideration of their sources, we may enumerate the chief waste products of protoplasmic activity as follows:

Waste Products.		Organs of Excretion.
Gaseous....	Carbonic acid.	Lungs, skin.
Liquid.....	Water.	Kidneys, lungs, skin.
Solid.....	Urea and other nitrogenous wastes.	Kidneys, skin.
	Inorganic salts.	Kidneys, skin.

Protoplasm is unable to extract energy from these substances, and their presence in the body in excessive quantities is harmful. Nature has therefore evolved in the organs of excretion refined mechanisms for removing them from the organism. They are cast out from the living cells into the blood, and are transferred by the circulatory organs to the organs of excretion. The latter will now be considered.

A. THE KIDNEYS.

The kidneys are the most highly specialized of the excretory organs. Their duty is to manufacture and pass out the *urine*. Urine is a clear yellow or brownish-yellow liquid, consisting of about 96·5 per cent. of water and 3·5 per cent. of dissolved solid substances. The solids are numerous, comprising organic bodies such as urea, uric acid, and creatinin, and inorganic salts such as various sulphates, phosphates, and chlorides. Their variety and relatively considerable quantity indicate the great importance of the kidneys as purifiers of the blood and thus of the body. The greatest interest centres in the organic solids, of which urea is the most abundant, because they represent the characteristic waste products of the destruction of the important proteid substance. The special peculiarity of urea and these other products is the presence within them of nitrogen; hence the urine is the medium through which the all-important nitrogen leaves the body. The average quantity of urine that is passed in twenty-four hours is one and a half quarts, but the quantity is subject to great variations, depending upon the weather, the character of the food, whether much water has been drunk, and the occupation of the individual.

Urine.

The kidneys are highly complicated glands whose structure is specially adapted to the removal from the blood of large quantities of water, together with solid substances. They consist of a mass of minute canals (the *uriniferous tubules*), and of blood capillaries, inextricably woven together. Each tubule begins in an enlarged cavity (the *Malpighian*

capsule) into which projects a tuft of capillaries, the *glomerulus*. From the capsule the tubule takes a tortuous course, as shown in the accompanying figure (Fig. 11), unites with other tubules, and finally approaches the surface of the kidney, where, together with all the other tubules, it opens into the dilated, funnel-shaped beginning of the duct, the *ureter* (Fig. 12). The wall of the tubule consists of a single layer of living cells varying in thickness in

Structure of the Kidneys.

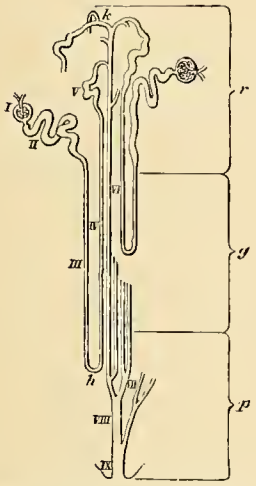

FIG. 11.—DIAGRAMMATIC VIEW OF COURSE OF URINIFEROUS TUBULES IN KIDNEY.

I, Malpighian capsule, containing glomerulus; *II–VIII*, course of tubule; *IX*, opening of tubule into pelvis of kidney at apex of pyramid of Malpighi; *k*, outer surface of kidney; *r*, outer or cortical substance; *g*, *p*, inner or medullary substance. (Huxley.)

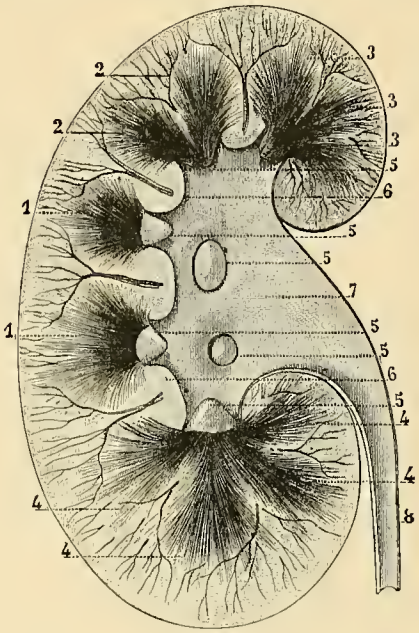

FIG. 12.—VERTICAL SECTION OF KIDNEY. (Somewhat smaller than natural size.)

1, 2, 3, 4, pyramids of Malpighi, striations representing uriniferous tubules; 5, apices of pyramids, where tubules open; 6, cortical substance projecting inward between pyramids and containing blood-vessels; 7, dilated end of ureter, called pelvis; 8, ureter. (Sappey.)

different parts. In among the tubules is the very close network of blood capillaries, and lymph permeates all the interstices. The tubules are thus bathed by the circulating fluids.

Most of the constituents of the urine exist ready formed in the blood, having been cast into it by the cells outside of the kidney. The process of excretion consists in a discharge of these substances through the cells that form the walls of the tubules. Some of the cells apparently have the power of manufacturing and casting out the few constituents that are not present in the blood. In its mode of action the kidney thus seems to combine the more

Excretion by the Kidneys.

clearly physical features of the work of lung cells and the more obscure secretory activities of gland cells, as represented by the digestive glands. The urine is secreted constantly, and trickles along the tubules to the dilated end of the ureter; it then leaves the kidney in the latter tube and passes to the urinary bladder situated in the pelvis. Here it accumulates until the distention of the bladder gives rise to a desire to micturate. Nervous impulses from the brain cause the muscular walls of the bladder to contract, and the urine is discharged from the body through the urethra.

B. THE SKIN.

The skin performs a variety of duties. It protects the delicate parts within the body; it contains organs for the senses of touch and of temperature; through its blood-vessels it regulates the temperature of the body; and it contains important excretory organs. The latter are the two kinds of glands known as *sudoriferous*, or *sweat*, glands and *sebaceous* glands; the former produce the sweat, the latter the oily substance found on the surface of the body.

Functions of the Skin.

Sweat glands are simple tubes the secreting portion of which, coiled into a knot, lies just beneath the skin (Fig. 13). The duct passes through the skin and terminates by a minute opening upon the surface. These "pores" may readily be seen by a common magnifying glass upon the fine ridges in the palm of the hand (Fig. 14). Sweat is a colourless, salty liquid

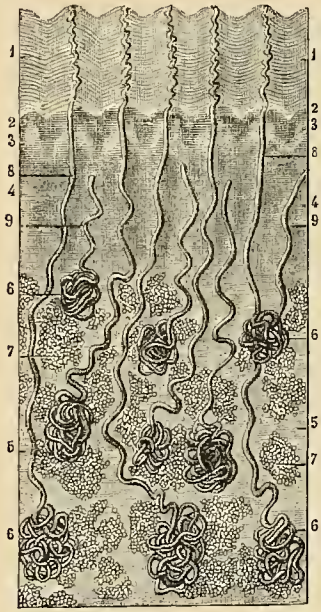

Fig. 13.—Vertical section of skin. (Magnified 20 diameters.)

1, outer layer of skin; 1, 2, cuticle or epidermis; 3, 4, inner layer of skin or dermis; 5, subcutaneous tissue; 6, sweat glands; 7, masses of fat, consisting of fat cells; 8, 9, ducts of sweat glands. (Sappey.)

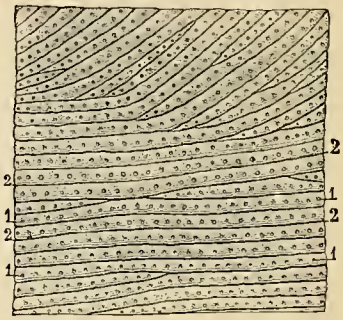

Fig. 14.—Surface of palm of hand. (Magnified 4 diameters.)

2, ridges in skin bearing (1) openings of ducts of sweat glands. (Sappey.)

consisting of water and slight quantities of urea, inorganic salts (especially common salt), and a few other substances. It is constantly given off. An average quantity is nearly a quart in twenty-four hours, but the amount varies greatly with the weather, the occupation of the individual, and other influences. The perspiration is thus seen to be an important medium of loss of substance from the body. This is especially evident when one exercises vigorously; it is easily possible in an hour's exercise to diminish one's weight by a pound. The more one perspires, the less the kidneys excrete, and *vice versa*. Hence the skin is more active in summer, the kidneys in winter.

Sweat Glands.

The sebaceous glands lie in the deeper part of the skin and open chiefly into the depressions in which lie the roots of the hairs. They secrete an oily substance of slight value as an excretion, but of use in preventing the skin and the hair from becoming too dry.

Sebaceous Glands.

C. THE LUNGS.

The expired air is an important medium of loss of water and the chief one for loss of carbonic acid. The excretory function of the lungs has been considered sufficiently under respiration.

We have followed the oxygen and the food—consisting of proteids, fats, carbohydrates, salts, and water—from without the body by way of the digestive organs and the lungs to the living cells. We have seen that waste matters in the forms of carbonic acid, urea, salts, and water go from the living cells by way of the excretory organs to the exterior. What takes place within the living substance?

Section V.

METABOLISM.

If we could answer the question propounded at the end of the last section we should know what life is; yet we are unable to point to any one of the millions of cells in the human body and say that we know all the details of the vital process that takes place within it. The difficulties and complexities of the problem are inconceivably great, but perhaps not insurmountable. We can measure and analyze the income and the outgo of the body; we can test the effect of different foods upon the general metabolism; we can observe how the composition of the different organs changes when food is withheld from the animal for a time, all of which methods are helpful. But, further than this, chemical investigation is revealing to us ever more clearly the steps in the pathway between food and wastes;

we are approaching a knowledge of the structure of protoplasm and of the structural changes that take place in the actively working cell; and recent studies of the action upon organisms of the environment and of external agents—such as light, heat, electricity, and chemical influences—are giving us a deeper insight into the secrets of the physical basis of life. We can conceive the nutritional changes that take place within the cells and that constitute the metabolic process as consisting of a building up and a breaking down. Raw material in the form of food that is rich in energy is brought to and absorbed by the cells. It is altered chemically, its atoms are recombined, and it is built up, probably by a complex series of steps, into protoplasm, its energy being retained in a latent form; this is the constructive phase of metabolism, called *anabolism*. Later, the protoplasm is changed chemically, its atoms are recombined, and it is broken down, probably by a complex series of steps, into wastes, its energy being given off in the form of mechanical work and of heat; this is the destructive phase of metabolism, called *katabolism*. Stated in these words, the vital process seems simple enough. But this is not the whole story; for, in the first place, not all the food is built up into protoplasm before it is broken down into wastes; some appears to be changed at once after entering the tissues and to be immediately cast out in the excretions; other food is stored up for a time, to be used subsequently for the manufacture of protoplasm or for other needs of the body. Fat is an excellent example of a substance that is thus stored; it is not living, but is contained within special living cells—the fat cells. The cells of the liver are likewise loaded with a variety of starch, called glycogen. Fat and glycogen constitute a stock of reserve material upon which the cells may draw in time of need. Further, each of the different varieties of cells has its own special metabolic peculiarities. For example, the digestive glands are peculiar in manufacturing in quantity substances (the digestive fluids) that are of the greatest subsequent value to the body; certain of the brain cells are unique in the fact that their activity is accompanied by phenomena of thought; the muscles seem to be the greatest producers of the body heat. All these peculiarities complicate the problem of metabolism greatly, and the real difficulty comes when we attempt to learn the details of the matter.

Metabolism in General.

The one fact that stands out above all others is the fact that the destructive or katabolic process is one of oxidation; that is, the gas, oxygen, is made to unite with the other elements—carbon, hydrogen, nitrogen, etc.—that exist in the food or in protoplasm. Thus, of the various excreted substances, carbonic acid is a compound of oxygen and carbon (in the proportions CO_2); water is a compound of oxygen and hydrogen (in the pro-

Katabolism is Oxidation.

portions H_2O); and urea, while more complex in composition (CH_4N_2O), is undoubtedly formed by oxidative processes from the still more complex proteids. In this vital process of oxidation heat and mechanical energy are set free for the body's use, hence the body is warm and can do work; and the excretory substances are therefore largely devoid of energy. Oxidation is nothing more nor less than combustion; the burning of wood or coal or illuminating gas is oxidation. The burning of these lifeless substances, therefore, and the vital processes, are fundamentally of the same chemical nature. So, too, as regards energy, coal, when burned in a furnace, yields heat, mechanical work, and light; protoplasm, when consumed in a living body, yields heat, mechanical work, and in certain animals, such as the firefly, glowworm, and some marine forms, even brilliant light. Such a parallelism between lifeless and living substance is interesting and suggestive.

Anabolism not Simple Absorption.

Another striking fact is that the living tissues do not convert unchanged into their own substance the substance of the corresponding tissues that are eaten in animal food. For example, the fat of the food does not go directly to form the fat of the body; the muscle proteid of beef or mutton that we eat does not form directly our own muscles, nor does the animal starch—glycogen—come directly from the starch of bread and vegetables. On the contrary, all of the food stuffs are worked over by the living substance, are resolved into other substances, and these other substances are recombined into the proteids, the fats, and the carbohydrates that are found in living matter. One practical application of this principle is found in the fact that the most certain method of increasing one's weight by fattening is not by eating large quantities of fat, but rather by living largely upon a carbohydrate diet (starch and sugar), since it has been found by experiment that such a diet leads directly to the formation of body fat. On the other hand, to reduce the fat of one's body, a diet rich in proteid is most effective.

Nutritive Uses of Various Food Stuffs.

As to the uses of the various food stuffs, it may be said that proteid in some form is always necessary in the food, since it alone of the chief food stuffs contains nitrogen, and nitrogen is an important constituent of protoplasm. Proteid is the chief source of the elements of new protoplasm, and hence the value of meats, eggs, and milk as articles of diet. Proteid also gives energy to the body, but it is an expensive food. Fat is very rich in energy, and protects the proteid substance within the protoplasm from destruction. It may with advantage take the place of some of the proteid in the food; "a streak of fat and a streak of lean" is not without physiological justification. Carbohydrates play a rôle similar to the fats in supplying energy. They are a cheaper food and are easily digested. The part that is played

in metabolism by inorganic salts, of which common table salt may be taken as the type, is not known. They exist in all the tissues, and they are constantly leaving the body in the urine and the sweat. Depriving animals of salt brings on weakness and even paralysis; yet most salts are not sources of energy. All that is known upon the subject may be summed up in the statement that protoplasm will not continue to do its work without salt. Hence salt is needed in the food to balance the loss through the excreta and thus to maintain a constant supply in the living substance. Nor is water a source of energy. Its presence everywhere in the body facilitates the chemical reactions, and all substances in passing from one part of the organism to another must be dissolved in it. It constantly leaves the body, partly for the purpose of regulating the body temperature, as we shall see later, and partly for the purpose of carrying off the solid part of the excreta. Without it protoplasm dies, and hence its necessity in the food.

Diet.

Much attention has been given to the determination of a diet most suitable for the average man, and it is now known with reasonable accuracy what such a man requires for his daily needs. A fair division of the various food stuffs is given below:

Proteids	4 oz.
Fats	2 oz.
Carbohydrates	17 oz.
Salt	1 oz.
Water	nearly 3 qts.

It is not a simple matter, however, to proceed from such a diet to the preparation of a suitable *menu*, for, although the proportions of food stuffs in the common foods are known (Fig. 15), it does not follow that all the food stuffs taken into the mouth are absorbed by the tissues. The digestibility of the foods is an important factor too often overlooked by rich and poor alike. A liberal allowance of beefsteak will not yield to the body four ounces of proteid unless it be so prepared that the digestive organs can deal with it. The digestibility of the various foods has not yet been determined with sufficient accuracy; the problem is a difficult one, complicated as it is by the idiosyncrasies of individuals and by the infinite varieties of method used in the preparation of foods.

Vegetarianism.

Scientific investigation and the common experience of mankind point to a combination of animal and vegetable foods as the most suitable diet. Meat and eggs are especially characterized by the presence of proteid in a concentrated form; to obtain the needed amount of proteid from vegetables would require the consumption of an excessively large quantity of food. A strictly vegetarian diet throws upon the digestive organs of man an excessive amount of labour.

This is not so in the case of herbivorous animals, since in them the teeth are specially modified for grinding, the alimentary canal is relatively long and large, and the digestive processes are adapted to their tasks. In man, however, the teeth are evidently degenerating, and the alimentary canal is becoming reduced in capacity, the evident outcome of which in time

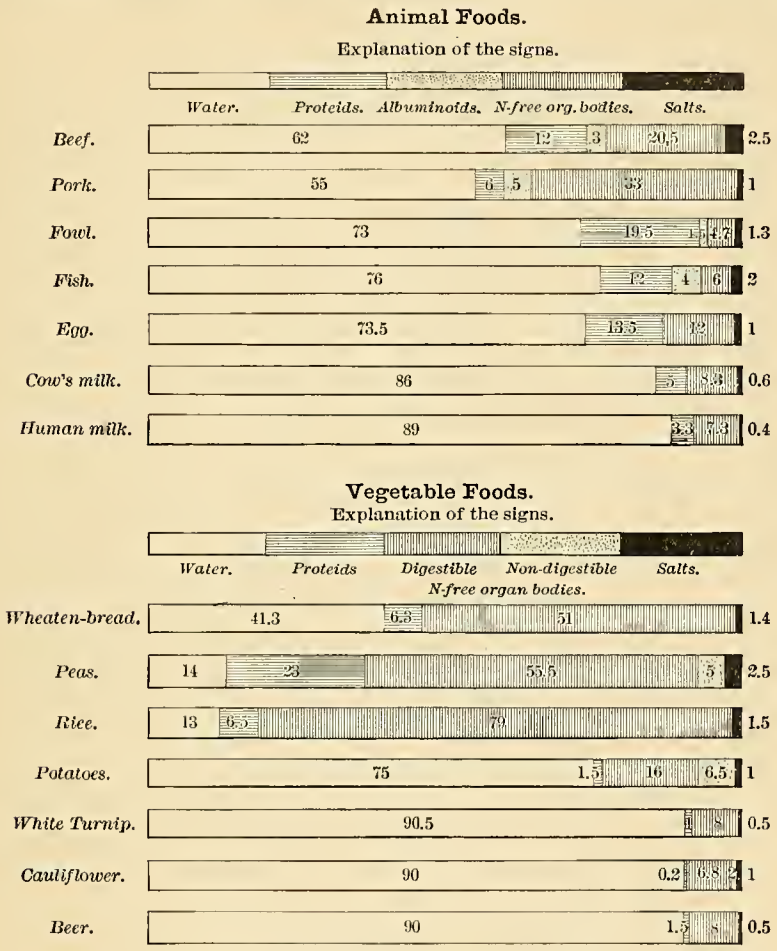

Fig. 15.—Composition of some common foods.
Nitrogen-free organic bodies include both fats and carbohydrates.

will be the necessity of less bulky, more easily masticated, and more easily digested food. The misguided vegetarians, in their endeavours to make man herbivorous, forget that that stage in his career was passed ages ago, that his body is no longer fitted for it, either anatomically or physiologically, and that stemming or turning back the tide of evolution is not without difficulties.

The two chief modes of manifestation of the energy of the body are through mechanical work and through heat. These may now be considered. Mechanical work is performed by the muscles, and comprises all work done by the hands and arms, by the legs in walking, by the trunk in lifting, by the larynx in speaking, etc. It is comparatively easy to measure approximately the amount of work performed by a man in a given task. It was supposed formerly that the energy for muscular work was derived solely from the nitrogen-containing proteid of the food and of the tissues. If this were so, and since urea is produced by the destruction of proteid, the quantity of urea given off from the body would be proportional to the amount of work done. Elaborate investigations made upon the pedestrian Weston, and other individuals, in order to test the question, have refuted the old idea and have shown that the main source of the energy of muscular work is not the proteids, but rather the fats and the carbohydrates. The hunger that follows labour does not, therefore, require for its satisfaction an increase of expensive proteid food. About one fifth of the total energy introduced into the body by the food appears again in the form of mechanical work, the remaining four fifths taking the form of heat. At first thought this would seem to indicate that the muscle is a poorly constructed machine. But a steam engine is able to employ for work only about one tenth of the total energy of the coal, the heat that is lost carrying off the other nine tenths. The human body as a machine for transforming energy is, therefore, much superior to the steam engine.

Energy of Mechanical Work.

Perhaps no fact in all human physiology is more striking than that the body of man is warm, and constantly warm during all seasons, even though the surrounding temperature may be excessively low. In this respect man is like all the mammals and birds and differs from all other animals. The terms "warm-blooded" and "cold-blooded" tell a part of the truth only; "warm-bodied" and "cold-bodied" are equally applicable. Yet a still more correct designation of the two classes of animals is that of *constant* temperature and of *changeable* temperature. An adult man's body has a temperature of about 98·6° Fahr., and normally varies rarely more than a degree above or below that point. A frog's body can not be said to possess a normal temperature. It is always cold to the touch, but varies within very wide limits, depending upon the temperature of the surrounding air or water. Heat is produced in all animal and plant bodies, but is dissipated at once to the surroundings in all organisms except the warm-blooded animals. The heat comes from the oxidation or burning of the food and body substance, and is derived from all three chief classes of food stuffs. Its production is a fundamental property of protoplasm, and takes place wherever living substance exists. Hence all organs and tissues yield heat; but the muscles, form-

Body Temperature.

ing as they do so large a proportion of the bulk of the body and being actively metabolic organs, are the greatest heat producers. The more active an organ is, the hotter it becomes. The blood, while producing little heat, performs the indispensable rôle of equalizing the body temperature. Receiving its own warmth from the tissues through which it courses, it warms the more sluggish parts, and in turn cools those whose temperature tends to become dangerously high. While heat is produced constantly, it is as constantly being lost. We warm our clothing and whatever we come in contact with that is of a lower temperature than the body; the air that we breathe out is warm; the excretions are warm; much latent heat goes off in the evaporating sweat. Of all these pathways of loss, the skin is the chief one, eighty per cent. of the lost heat leaving the body through it.

Regulation of Body Temperature.

As has been seen, a warm-blooded animal differs from a cold-blooded animal in the fact that the temperature of the body of the latter changes with that of the surroundings, while that of the former remains practically constant. The cause of this difference lies in the fact that in the warm-blooded organism both the production and the loss of heat are carefully controlled by the nervous system. As regards production of heat, the lower the temperature of the air the more heat the body produces, partly through invisible, obscure metabolism, partly through visible muscular movements, such as shivering; on the other hand, the higher the surrounding temperature, the less active are the muscles. As regards loss of heat, the lower the temperature of the air, the less blood goes to the skin, and hence the less heat radiates from the surface; on the contrary, the higher the temperature of the air, the more the cutaneous vessels dilate and allow the heat of the blood to pass off; at the same time the body perspires and gives out abundant latent heat in the sweat. Thus the vaso-motor nerves, the secretory nerves of the sudoriferous glands, and other nerves are employed for heat regulation, and their various activities are brought into harmony through the central nervous system. In the cold-blooded organism no such regulating mechanism exists.

Functions of the Liver.

In discussing metabolism the liver must not be overlooked, since it plays so important and such various rôles in nutrition. We shall here enumerate its chief functions. The liver produces bile, the use of which in the digestion of fats we have discussed. In addition to this digestive property bile contains several complex substances which must be regarded as waste products of protoplasmic activity, and are passed off from the body with the undigested food matters; hence the liver is an organ of excretion. The liver cells contain abundant glycogen, or animal starch, which is regarded as a reserve stock; hence the liver is a storehouse of carbohydrates.

Lastly, the liver seems to be the chief organ in which take place the final processes in the manufacture of urea; the raw material for excretion comes in the blood from the various organs to the hepatic cells, the cells transform them, and the finished product, urea, is transferred to the kidneys for elimination. With such a multiplicity of functions it is not surprising that "liver complaints" form so large a proportion of human ills.

The spleen, the thyroid body, the suprarenal bodies, and the thymus have apparently important metabolic functions, but their exact rôles are little known. At present they are being actively studied.

Our story of nutrition is completed. It is but the preliminary to a study of what may be called by some the higher functions of the body. To these we now turn.

CHAPTER II.

MOTION.

Section I.

MUSCLE IN GENERAL.

Motion in General.

Next to producing heat, the chief mode in which the body employs its stock of energy is by doing mechanical work. The physical sign of mechanical work is motion. Its manifestation is most evident in the day labourer. But the professional man and those who are known technically as brain workers are not simply heat producers. Aside from the ordinarily invisible involuntary movements of the organs and the visible voluntary movements of the body, without which no man passes through each succeeding twenty-four hours, the man who thinks gives his thoughts to the world in writing or speaking or acting, all of which are processes of movement. The organs of mechanical work are the muscles. A muscle is made up of muscle tissue and this in turn of muscle cells. Muscle cells always have one axis considerably longer than the other two, from which fact they are often called fibres, and the essence of their activity consists in their power of contracting or shortening in the direction of the long axis; in this process movement of attached parts is caused. This power of contractility is one of the fundamental attributes of protoplasm; it is possessed by the living parts of plants and by the one-celled animals. As the evolution of animal life in past ages went on and one-celled animals gave rise to many-celled animals with a variety of functions, the ability to contract became progressively stronger in some cells than in others.

In these contractile structure and function went on developing together, they became more and more perfected as organs of movement, and they gave rise finally to the highly specialized muscle cells that organisms possess to-day.

Structure and Varieties of Muscle.

When we look over the whole animal kingdom we recognise a very great variety of muscle tissue, from the simple cells of the jelly fishes, where only a part of the cell can be called muscular, to the highly differentiated muscle fibres of actively moving organs like the wings and legs of insects and the limbs of the higher animals. Notwithstanding this variety, muscle cells, especially in man and other vertebrates, may be grouped into three chief classes that are distinguished from each other both structurally and functionally. These are known, respectively, as *smooth*, *striped*, and *cardiac* muscle cells or fibres. *Smooth* or *unstriped* muscle fibres are so called because, in distinction from the other two varieties, they are not cross-striped (Fig. 16). They are usually spindle-shaped; they are most common in tubular organs, occurring in the walls of the alimentary canal, the arteries and the veins, the ducts of glands, the trachea, and in general in those parts of the body, except the heart, that are capable of involuntary movement only. They are bound together by connective tissue into muscular coats encircling the tubes in whose walls they lie, and by their contraction they constrict the tubular organs. They are not under the control of the will. They are the most primitive of the three kinds of muscle substance. Their action is slow, as is indicated by the writhing, wavelike movements of the stomach and the intestine during digestion. *Striated* or *striped* muscle fibres are so-called because, when examined with the microscope, they appear indistinctly cross-striped with alternate lighter and darker bands (Fig. 17). They are very long, delicate, threadlike cells, and their protoplasm is highly complicated in structure. They are usually under the control of the will, and form the flesh or meat of the body—that is, the muscles of the arms, the legs, the head, and the trunk. Each muscle consists of a mass of innumerable fibres bound together by connective tissue into bundles, and is attached usually to bones by means of tendons. Striped muscle is the most highly specialized kind of muscle tissue. It is capable of very quick action, as is shown by the rapidity with which one can strike a blow or play a piano. *Cardiac* muscle is intermediate

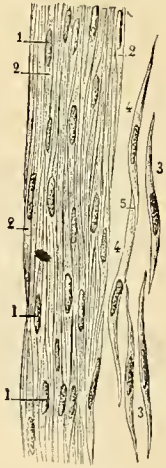

Fig. 16.—Unstriped muscle fibres of man. (Magnified 200 diameters.)
1, nuclei of fibres; 2, fibres in mass; 3, isolated fibres; 4, 4, two fibres joined together at 5. (Sappey.)

structurally between the other two. It consists of short, compact, indistinctly striped cells. It occurs only in the heart, and, as we have learned in studying the heart beat, contracts spontaneously, involuntarily, and rhythmically.

For the past fifty years muscle has been a fascinating and fruitful field of physiological research. Many of the most interesting and fundamental problems of general protoplasmic action have been and may be studied here more successfully than in other tissues; not only the laws of vital movement, but fundamental questions such as automaticity, irritability, rhythm, animal electricity, and the chemical phenomena of life. A large variety of delicate and valuable apparatus has been devised for the exact investigation of these various problems. The study of striped muscle has yielded the most information, and our present discussion will be limited to this. As has been stated, the essence of muscular action consists in the power of the muscle fibres to contract. In cold-blooded animals, such as the frog, the muscles retain their contractile power—that is, remain living—long after the animal has been killed, hence it is easy in such animals to study muscular action. During life the muscles are made to contract through impulses coming to them along the nerves from the brain or spinal cord. After death in cold-blooded animals they may be stimulated to activity by electric shocks, heat, pinching, or by certain chemicals applied either to the muscles directly or to their nerves. For each stimulation the muscle gives a single twitch or contraction, during which it shortens and becomes thicker and harder, and then immediately relaxes into its former state. The whole period of activity occupies only about one tenth of a second, yet during this moment the muscle undergoes profound molecular changes. Besides the mechanical changes spoken of, it produces heat and becomes warmer, produces carbonic and lactic acids, and develops a considerable electric current. All these phenomena indicate what great metabolic changes muscle protoplasm is subjected to during activity. It would be interesting to trace these further, but it would take us beyond our present space. In life it is probable that voluntary muscle rarely, if ever, gives

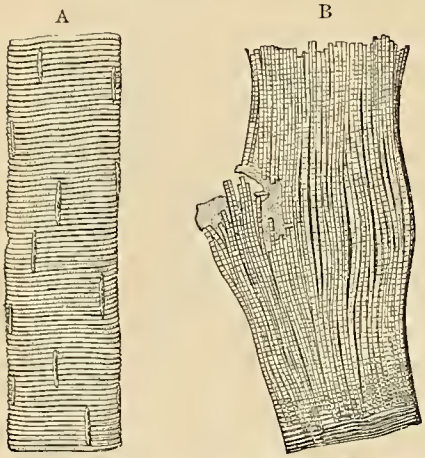

FIG. 17.—STRIPED MUSCLE FIBRES. (Magnified 250 diameters.)

A, piece of a fibre showing cross-striations and nuclei; B, piece of a fibre with cell-wall (sarcolemma) ruptured, showing tendency of fibre to split into fibrillæ. (Sappey.)

Action of Muscle.

single isolated twitches. Each contraction, however quick, consists of numerous single contractions following one another at the rate of about twelve in the second, and becoming fused into a compound contraction called *tetanus*. These rapid contractions give rise to a dull booming sound which is emitted by the muscle and may readily be heard by inserting the tips of one's fingers into the ears and contracting strongly the muscles of the arms. In health the muscles always seem to be in a state of slight contraction, or "tone," which accounts in great part probably for the elasticity, springiness, and ready muscular response of the athlete. This healthy tone appears to be due to nervous impulses coming constantly to the muscles from the spinal cord. It is noticeably absent in ill health. Many muscles are so placed as to antagonize the actions of others. For example, the flexors, which bend the arms, legs, fingers, and toes, act in opposition to the extensors which straighten the same parts; the eye is closed by the orbicularis and opened by its antagonist, the levator of the upper lid; and the delicate adjustments of the parts of the larynx in speaking and singing are due to refined balancing of opposing muscles.

Muscular Tone.

Section II.

SPECIAL MUSCULAR MECHANISMS.

As instances of special motor phenomena we have already mentioned the digestive movements, the beat of the heart, arterial constriction and dilation, and the movements of respiration. We may now notice briefly a few others.

A. LOCOMOTION.

The erect posture in standing or sitting requires the co-ordinated action of numerous muscles of the trunk and the legs. That this is so is evident from the fact that the body collapses whenever, as in fainting, the muscles fail to receive their customary stimulating impulses from the central nervous system.

Walking is a complicated muscular act, participated in by a large number of muscles of the legs, the trunk and the arms, that contract in regular sequence (Fig. 18). Each leg is flexed as it is swung forward like a pendulum; it is then straightened and serves as a support for the swinging trunk. The movements of the trunk are peculiar. It alternately rises and sinks, in falling forward, and sways from side to side as the centre of gravity of the body comes now over the right, now over the left foot; at no time is the body wholly free from contact with the ground, and for a brief interval, when the feet are farthest apart, both feet touch it at the same time. In running, the sequence of events is so

far different from that in walking that at one time the body is entirely free from support. The recent advances in the art of instantaneous

Fig. 18.—Series of figures from instantaneous photographs to illustrate movements in slow walking.

All phases of movement of the right arm and leg are shown in figures I to VI. Arabic numerals indicate the corresponding positions of the left arm and leg; thus position III of the right side is simultaneous with position 6 of the left side. (Marey.)

photography have added much to our knowledge of the mechanism of bodily movements.

B. FACIAL EXPRESSION.

Changes in facial expression are muscular phenomena, due to contraction of the facial muscles in combinations varying with the various emotions. This is shown by the fact that it is easy by electrical stimulation of the muscles through the skin to produce artificially in an individual at will a desired emotional expression (Fig. 19). The anatomical peculiarities of the face constitute the features and give a certain set to every countenance. The expressions are physiological, and are produced in much the same manner in different individuals. In his book, entitled *The Expression of the Emotions in Man and Animals*, Darwin has given the results of a careful study of expression. He analyzes into their various muscular components the changes accompanying joy, grief, despair, love, hatred, anger, disdain, contempt, pride, surprise, fear, horror, etc. He finds the origin of many of these expressions in the lower animals, and shows how they have gradually become habitual and

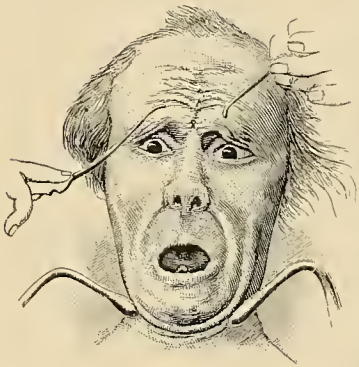

Fig. 19.—Expression of extreme terror.

Produced artificially by stimulating with electricity the muscles of the forehead and the jaws. The four curved rods are the stimulating electrodes laid upon the skin over the muscles. (From Darwin, after Duchenne.)

innate in man. Their primary purpose was not to reveal emotional states of mind, but rather they were either of some direct bodily benefit to the

FIG. 20.—EXPRESSION OF VARIOUS EMOTIONS, SHOWING CHARACTERISTIC MUSCULAR CONTRACTIONS. A, pride and defiance; B, helplessness; C, childish joy; D, childish grief. (A and B from Darwin after Duchenne.)

individual or were indirectly the effect of a general excitement of the nervous system. (See Fig. 20.)

C. VOICE.

The production of voice is the most delicate of all muscular acts of which the human body is capable. The larynx, the organ of voice, is the modified upper end of the trachea. However much the voice may seem to arise at the lips, or in the mouth, or in the chest, it is only modified by these parts, and the sound is produced in the larynx only. Considered as a musical instrument, the larynx is most nearly like a reed instrument, of which the clarionet is an example; but the resemblance is not close. In the larynx the parts that correspond to the reeds, by the vibration of which voice is produced, are the two vocal cords (Fig. 22). They are elastic membranes that extend from each side horizontally toward each other into the cavity of the hollow larynx, and are stretched more or less from before backward. They do not meet in the middle line, but have between them a chink of variable width, the glottis, extending across the larynx from front to back. Each cord is thickened with muscle at its outer part attached to the walls, but its free edge at the glottis is thin, and consists of white, tough, elastic connective tissue. Thus the air-passage to and from the lungs is obstructed at its upper end by this horizontal membranous partition, with a passageway for air between its two halves. During ordinary silent breathing this obstruction is slight, for then the vocal cords recede to the side walls of the larynx and the glottis is wide open. During speaking or singing the cords are extended in toward each other and the glottis is reduced to a mere slit.

Physiological Anatomy of the Larynx.

Voice is the sound produced by the rapid vibration of the thin edges of the cords as the air rushes between them in expiration. The essential conditions of the production of voice are that the cords must be taut and their edges must be approximately parallel. These conditions are fulfilled through the various delicate muscles acting upon the cartilages to which the cords are attached, or even upon the cords directly.

Conditions of Voice.

The natural pitch of a voice depends upon the natural length and tension of the cords. Variations in pitch are produced by varying either the degree of tension or the length of the vibrating cord, or by varying both together. Thus, for the low tones, the more tightly the cords are stretched the higher the note, just as is the case in tuning a violin. For the high tones, the cords do not usually vibrate along their whole length; a portion, usually the posterior, is "stopped" by the cords being brought into contact with each other, and the anterior part only is capable of acting (Fig. 22, B), just as in playing the violin the pitch is regulated by placing the finger upon the string. Loudness of voice is determined by the strength

Pitch, Loudness, and Quality.

of the outgoing current of air. The quality of the voice—that by which we distinguish one voice from another and recognise the voices of our friends—depends upon the make and the age of the individual larynx, its size, the quality of the cords, and the shape, the size, and the mutual relations of the accessory vocal organs, such as the mouth and its parts, the nose, the pharynx, and the chest; in like manner the quality of tone

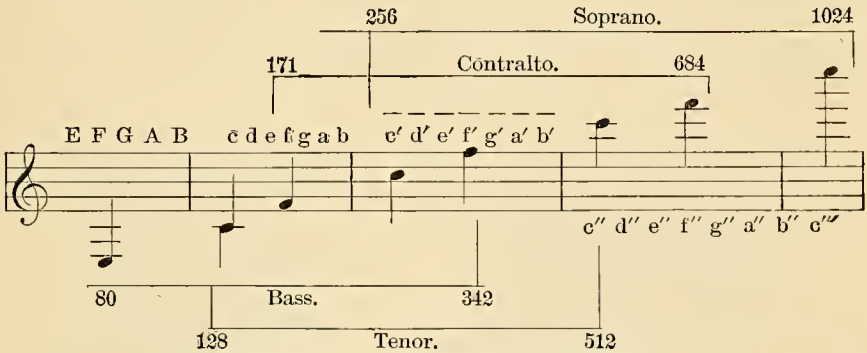

Fig. 21.—The average range of human voices.
c′ to f′ is common to all voices. The figures indicate the number of vibrations per second in the corresponding tones. (Landois and Stirling.)

of a violin depends upon age, the peculiarities of the grain of its wood, and the shape, size, and connections of the various parts of the instrument.

Control of the Voice.

The muscular adjustments necessary in producing all the wonderful variations in tone and in quality of which the human voice is capable are inconceivably delicate. Not only the muscles of the larynx, but those of the various accessory vocal organs, the tongue, the lips, the palate, and the pharynx, and the respiratory muscles, contribute their share in the process. All of these muscles are under the most careful nervous control, and, as we shall see later, a particular area of the brain has as its special duty the management of the vocal organs. The training of the voice is a training of these nervous and muscular mechanisms. That which determines whether a voice shall be called soprano, contralto, tenor, or bass, is partly the natural length of the vocal cords and partly the general nature of the vocal mechanism. The average range of the individual voice is two to two and a half octaves; the relative pitches of the four kinds of voice are shown in the accompanying table (Fig. 21).

Vocal Registers.

In singing a scale we are conscious of the necessity at certain notes of rearranging our vocal organs if we wish to produce well-rounded tones and prevent the voice from breaking. Such adjustments take place at different notes for different individuals. The compass that is possible for each adjustment constitutes

the so-called "register." Vocal teachers detect several registers, but physiologists recognise commonly two—the chest register or voice, and the head register or voice. The former, employed for low notes, is characterized by richness and fulness of tone; the latter, employed for high notes, is thinner. The difference in the mechanism of the two is not fully understood, and is perhaps not the same for all individuals. The appearance of the vocal cords during the production of voice, as shown by the laryngoscope (a small mirror placed in the back of the mouth and reflecting a bright light down into the larynx), is presented in the accom-

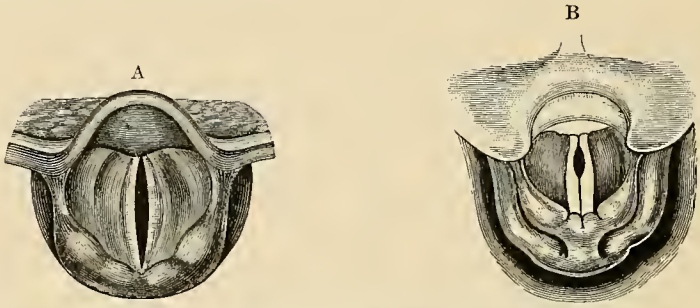

Fig. 22.—Interior of larynx, as seen by laryngoscope, during production of (A) chest-voice (Mandl and Grützner), (B) head-voice (Mills).

The glottis is represented as a black longitudinal slit in the middle of the figures, long in A, short in B; the vocal cords are shaded in A, white in B; the curved body at the upper part of the figures is the epiglottis; the rounded elevations at the lower part of the figures are cartilages.

panying figure (Fig. 22). The mechanism of the falsetto voice in man is also in dispute. The breaking of the voice in boys at puberty is caused by the rapid growth of the larynx and the constant congested condition of the vocal cords.

Speech is voice modified by changes in the accessory vocal organs, especially the resonance cavities, the pharynx, the nasal cavities, and the mouth. The sounds of speech are classified into vowels and consonants. All vowels have the same laryngeal sound as their basis; but for each vowel, by changes in the shape of the resonance cavities, different overtones are added to the fundamental laryngeal tone, hence the difference in the sounds. Consonants are noises produced mainly in the mouth by modifications of the outgoing current of air. Some are and some are not accompanied by vocal sounds. In gutturals (K, G) the modification is produced by the soft palate and the root of the tongue; in dentals (T, D, S, L, Z, N, R) by the tip of the tongue near the teeth; in labials (P, B, F, V, M) by the lips. The details of the mechanisms of the consonants must be omitted.

Speech.

Section III.

NON-MUSCULAR MOTOR MECHANISMS.

Muscle is not the only motor tissue that is found in the human body. There are two other varieties of contractile cells that in a very unostentatious way perform mechanical work and are indispensable to the body's welfare. These are amœboid cells and ciliated cells.

Amœboid Cells.

Amœboid cells comprise the colourless corpuscles of blood and of lymph (Fig. 4, G), and are so called because they resemble and are capable of moving about from place to place like the simple one-celled animal, *Amœba*. Reference has already been made to their function.

Ciliated Cells.

Ciliated cells are epithelial cells, and are fixed in position with one end exposed to the cavity which they line. This uncovered end bears a tuft of minute, delicate, hairlike filaments (the cilia) that project into the cavity (Fig. 1, E). During life the cilia are in constant, rapid, wavelike motion, sweeping along whatever substances come in contact with them. They are especially useful in carrying from the lungs toward the mouth and the nose mucus, and with it inhaled particles of dust. They line not only the bronchial tubes, the trachea, the larynx, and the nasal cavities, but the ducts of certain other organs, and, being in incessant action throughout the lifetime, they accomplish a large amount of labour.

CHAPTER III.

THE NERVOUS SYSTEM.

Nervous System in General.

It would be a sorry community of people wherein every individual worked for himself alone, regardless of the wants and the welfare of others, and wherein there existed between individuals and between professions no social and no commercial intercourse. A continuance of such a state of things would be impossible unless the community were composed of few individuals and such as were content to remain low in the scale of civilization. The same principles apply to a community of protoplasmic cells and organs; if there be no intercellular and no interorganic comity and exchange there is no rising in the scale of organisms. We have seen that in the human body the mutual interactions of the various parts are excessively complex, and this complexity is carried so far that no part is able to live when separated from the body. In both the community of people

and the organic community an agent is needed to control the relations of individuals. Such an agent exists in the system of government of the one and the nervous system of the other. In every body of men that has taken rank above the lowest a government exists, while in every protoplasmic animal organism above the simplest there is a nervous system. The subordinate position in the organic world that is accorded to plants is due more than all else to their lack of nervous organs. The nervous system is at once the servant and the master of all the other systems; it responds to the needs of one by controlling the work of another; thus it coordinates and harmonizes, and makes one of many. But it attends not only to internal affairs: it keeps the organism apprised of what goes on without, and thus enables the body to adapt itself to its environment. It is, finally, the medium of all mental life. To accomplish all this it must of necessity be complicated both in its anatomy and in its mode of working. No system in the body is more complicated. None is more difficult to investigate and to understand. The nervous system of man comprises the central nervous system, consisting of the brain and the spinal cord, and the peripheral nervous system, consisting of the nerves and the ganglia. A portion of the peripheral system is known as the sympathetic system, though this can not be regarded as physiologically independent of the rest. To this enumeration must be added the organs of the special senses; these are so unique as to justify treatment in a separate chapter. The different parts of the nervous system have very different structures and functions, such that the whole may be regarded as a union of numerous complex organs; but notwithstanding the complexity, the elements of structure

FIG. 23.—DIAGRAM OF A TYPICAL NEURON. *b*, cell body; *d*, dendrites, or protoplasmic processes; *a*, axis-cylinder process, or nerve fibre.

and of function are fundamentally the same throughout all parts. Within the past ten years remarkable advances in our knowledge of nervous structures have been made.

Elements of Nervous Structure.

The elements of nervous structure are the nerve cells, or *neurons*, as they are now coming to be called. Neurons vary in shape, but each consists of a cell body and processes extending from it (Fig. 23). The cell body consists of protoplasm and a large nucleus. The processes may be of two kinds, called *dendrites*, or *protoplasmic processes*, and *axis-cylinder processes*. The dendrites are much-branched, short filaments. The axis-cylinder process, usually one in number for each cell, is the most highly specialized part of the neuron. It has few branches, and may be very long (three to four feet). Near its end it splits into numerous fine filaments that terminate in the vicinity of the cells supplied by the neuron, whether they be muscle cells, gland cells, sense cells, or other neurons. The brain and the spinal cord are masses of neurons bound together by connective tissue and richly permeated by blood-vessels. It was formerly supposed that the processes are joined together into an inextricable network, and that nervous impulses, in passing from one part of the nervous system to another, traverse this maze. But recent discoveries have made it reasonably certain that there is no network whatever; that, on the other hand, every neuron is independent of every other, and that a nervous impulse passes from one to another through contact, and not through continuity of their respective processes. In some parts of the brain and the spinal cord cell bodies and dendrites predominate and constitute the *gray matter;* in other parts axis-cylinder processes only exist, constituting the *white matter*. Nervous ganglia are masses of cell bodies. Nerves are bundles of axis-cylinder processes arranged parallel to each other, each process being ensheathed usually in a fatty covering called the medullary sheath. The axis-cylinder process

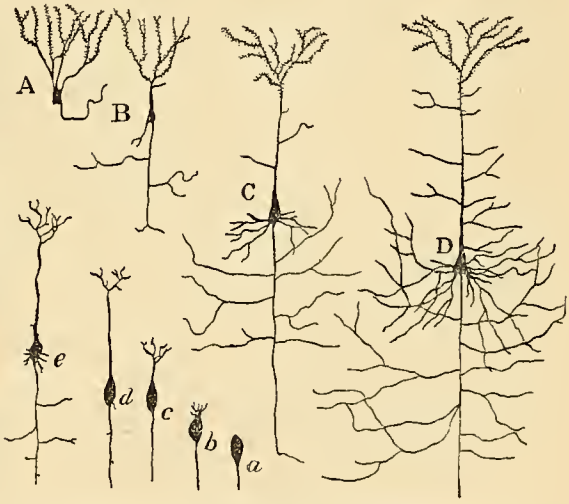

FIG. 24.—PSYCHIC BRAIN CELLS IN DIFFERENT STAGES OF EVOLUTION.

A, frog; B, newt; C, mouse; D, man. Series *a* to *e* shows the stages that a single brain cell of a higher vertebrate passes through in its growth. (Baker, after Ramón y Cajal.)

and its protecting sheath form a *nerve fibre*, and every nerve is composed of numerous nerve fibres. In the embryo nerve cells arise as compact bodies. The processes appear as outgrowths from them, and continue to grow in length and complexity during embryonic life and adolescence. It is a significant fact that the neurons are more complex the higher they are in the animal scale (Fig. 24).

Elements of Nervous Function.

The elements of nervous function comprise the functions of the body of the neuron and those of the processes. The cell body is the central organ of nervous energy. It receives, originates, and gives out nervous impulses. In most neurons the activity of the cell body is wholly unconscious, but in those existing in the superficial layers, the cortex of the cerebrum, mental phenomena accompany the nervous actions, hence such neurons are called *psychic*. The processes of the nerve cell are specialized to conduct nerve impulses, the dendrites conducting probably toward the cell body, the axis-cylinder process in some cells away from, in others toward, the cell body. Nerve cells are usually said to act either automatically or reflexly. An *automatic* action is one in which the impulse originates in the cell body as the result of chemical or other changes, and passes thence along the axis-cylinder process to the end organ (Fig. 25). The respiratory centre is said to act automatically. The psychic cells are called automatic. It is a question whether automatism in this sense is at all a common phenomenon. A *reflex* action is one in which the nervous impulse originates outside of the nerve cell, passes to the latter, is there elaborated, and then passes on as before to the end organ (Fig. 25). A typical example of a reflex action is that of winking: a foreign body touches the eyelashes or the eyeball; this causes nervous impulses to go to the nerve cells that control the muscles of the lids; return impulses

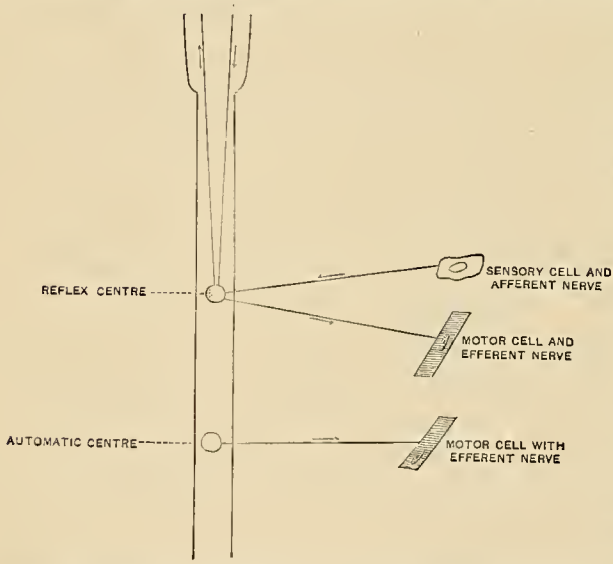

FIG. 25.—DIAGRAM TO ILLUSTRATE NERVOUS MECHANISM IN (1) AUTOMATIC ACTION, (2) REFLEX ACTION, (3) PASSAGE OF SENSORY IMPULSE UPWARD AND OF MOTOR IMPULSE DOWNWARD WITHIN CENTRAL NERVOUS SYSTEM. (Mills.)

come back to the muscles, and the lids close. Reflex actions are involuntary. The greater part of the body's actions are reflex; not only the unconscious movements that we are making constantly by means of our skeletal muscles, but also the muscular movements of the viscera and secretion in glands. The term "reflex arc" signifies the anatomical apparatus required for a reflex action. It consists of (1) a sensory end organ; (2) an afferent nerve fibre; (3) its associated nerve-cell body; (4) a second nerve-cell body in functional connection with (3), and giving rise to (5) an efferent nerve fibre; (6) a motor end organ, usually a muscle.

Nerve Centres and Nerve Conductors.

Thus we see that, physiologically, the nervous system consists of innumerable nerve centres and nerve conductors. The bodies of the nerve cells are the centres; the processes, especially the axis-cylinder processes, are the conductors. Considered *en masse* and roughly, the gray matter of the central nervous system and the ganglia outside of it have the functions of centres; the white matter of the central nervous system and the nerves are conducting in function. No fibre conducts in more than one direction. The nerve fibres outside of the brain and the spinal cord may be divided into two great classes, according as they conduct impulses toward the central nervous system or away from it; accordingly, they are known either as *centripetal* or *afferent*, or as *centrifugal* or *efferent* fibres. Most nerves are composed of both kinds. In the case of the spinal nerves a separation of the two kinds takes place at the junction of the nerve and the spinal cord, such that the posterior or dorsal root consists of afferent, the anterior or ventral root of efferent fibres. An afferent impulse, upon arriving at its centre, may simply give rise at once to an unconscious efferent impulse, producing a reflex action, or, with or without doing this, it may pass upward to the brain and give rise to a sensation (Figs. 25 and 26). Correspondingly, an efferent impulse may either arise in a lower reflex centre, as the direct result of an afferent impulse, or it may arise high up, even in the psychic part of the brain, and pass downward and outward, giving rise to a voluntary act. Hence, in harmony with the classification of peripheral fibres into afferent and efferent, there occurs within the brain and the cord a distinction between such fibres as conduct upward toward the cerebrum and such as conduct downward from the cerebrum. The former are really paths for the continuation of the afferent impulses coming

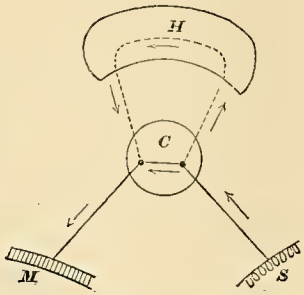

FIG. 26.—DIAGRAM INTENDED TO SHOW THE RELATIONS OF THE BRAIN, THE SPINAL CORD, AND THE PERIPHERAL ORGANS.

S, sensory end organ; *C*, spinal cord; *M*, motor end organ (muscle); *H*, hemisphere of brain. (James.)

from the outside to the psychic cells, where the impulses may give rise to sensations; hence afferent nerve fibres and those that conduct upward within the brain and the spinal cord are often called *sensory*. On the other hand, the downward impulses within the central nervous system are destined in large part for the muscles, and pass to them along the efferent nerve fibres, hence such conducting paths are called *motor*. The same terms apply to the cell bodies which the fibres join. The distinction between sensory cells and motor cells, sensory fibres and motor fibres, sensory centres and motor centres, and sensation and motion as nervous functions, is one of the most fundamental distinctions in the physiology of the nervous system. It is a curious and as yet not explained fact that the sensory parts of the brain and the spinal cord lie, in general, dorsal or posterior to the motor parts.

Sensory and Motor.

We have now presented the elements of nervous action. The central nervous system is a collection of central stations for the receipt, transformation, and transmission of nervous energy. Each of these stations has its own specific function, but they are joined with each other in the most intricate manner, and they are continually modifying each other's work. In ascending from the lower to the higher parts of the nervous system there is a progressive correlation of functions and a supervision of the lower by the higher centres. At the top in the cortex of the cerebrum lie the psychic cells, which are the physical media of mental life, the seat of the sensations and the place of origin of voluntary acts, and which are able to control the acts of all the lower centres (Fig. 26). To this elaborate mechanism stream constantly through sensory nerves impulses from all parts of the body and from the organs of the special senses, giving information regarding the condition and the needs of the various organs and tissues and the occurrences of the outside world. The ultimate possible goal of these impulses is the cortex of the cerebrum, there to give rise to sensations. But very few of the impulses reach this goal. Those to which the attention is directed, those which are unusually or excessively strong, or which for other reasons require consideration by the mind, pass to the cortex. The great majority, however, are dealt with by the lower centres. Wherever the impulses terminate they act upon sensory centres; these in turn stimulate motor centres; and, largely as the result of the incoming stream, there is as constant an outgoing stream of motor and other impulses through efferent nerves to the tissues and the organs. These outgoing nervous impulses regulate the actions of the various parts and of the body as a whole. Let us now consider the parts of the central nervous system more in detail.

Summary of Nervous Action.

As we ascend through the series of vertebrate animals in the order,

fish, reptile, bird, mammal, man, we find that there is a progressive increase in the weight of the brain as compared with the weight of the body. This is shown in round numbers in the accompanying table (Waller):

Comparative Importance of Brain.

	Weight of brain.	Weight of body.
Fish	1	5,000
Reptile	1	1,500
Bird	1	220
Mammal	1	180
Orang-outang	1	120
Man	1	50

Moreover, there is a progressive increase in the size of the brain as compared with the spinal cord; within the brain there is a progressive increase in the size and complexity of the higher parts as compared with the lower; and, lastly, there is a progressive increase in the size and relative importance of the cerebral cortex. This last fact is to be correlated with the gradual evolution and perfecting of mind, while the facts together mean that in general there is a progressive subordination of lower to higher centres. Accordingly we find, in ascending the series, a gradual limiting of the work of the lower parts.

A fish or a frog will continue to live for days after the brain is wholly destroyed if the spinal cord be left intact. This is impossible in the case of man. The human spinal cord is pre-eminently the central nervous organ for the reflex actions in which the spinal nerves take part, hence for the actions of the limbs and the trunk (Fig. 27). The "tone" of the voluntary muscles depends upon it. It contains respiratory, vaso-motor, and other centres which are accessory to more powerful ones in the medulla oblongata. Obviously it is also the path of conduction of impulses between the spinal nerves and the brain. The majority of these impulses ascend and descend upon the side of the cord from which their nerves arise. A few cross over to the opposite side.

Spinal Cord.

The medulla oblongata and the rest of the brain stem contain the reflex centres of the cranial nerves and various other automatic or reflex centres; they regulate the movements of the eyes, the face, the tongue, the alimentary canal, the heart, respiration, the arteries, the larynx in speaking, the pharynx and œsophagus in swallowing; they also control the secretion of saliva and other digestive fluids. The brain stem serves also, like the spinal cord, as a path of upward and downward impulses. It is a curious fact that both sensory and motor impulses here cross over from one side of the brain to the other; hence the left side of the cerebrum deals with the right half of the body, and *vice versa.*

Brain Stem.

The function of the cerebellum is commonly believed to be that of harmonizing or co-ordinating the actions of the muscles. Injury to this part of the brain results in irregularity and uncertainty of bodily movements. But experimental evidence has not made it clear exactly how the organ acts.

Cerebellum.

Exact knowledge regarding the functions of the optic thalamus and the corpus striatum is quite wanting.

The cortex of the cerebrum is spoken of as the "seat" or the "organ" of consciousness and of intelligence; its cells form the physical basis of mental phenomena. When a man thinks, his cortical cells act; and if the latter be destroyed, mental phenomena seem to cease so far as that individual is concerned. We can only speculate as to the kind of relation that exists between the cerebral and the mental processes; so far as we know, the latter are always accompanied by the former. As experimental physiologists we search for the cerebral processes, and we find that apparently they do not differ from those that take place in any mass of nerve cells whose activity is unaccompanied by consciousness. Structurally the cortex is unique, being characterized by the presence of the large, much-branched pyramidal cells that occur nowhere else in the organism (Fig. 28); in details it differs in different parts. Formerly it was believed that the cortex acts as a whole, but modern research has shown the untenability of this view, which, indeed, seems now opposed to common sense.

Cortex of Cerebrum.

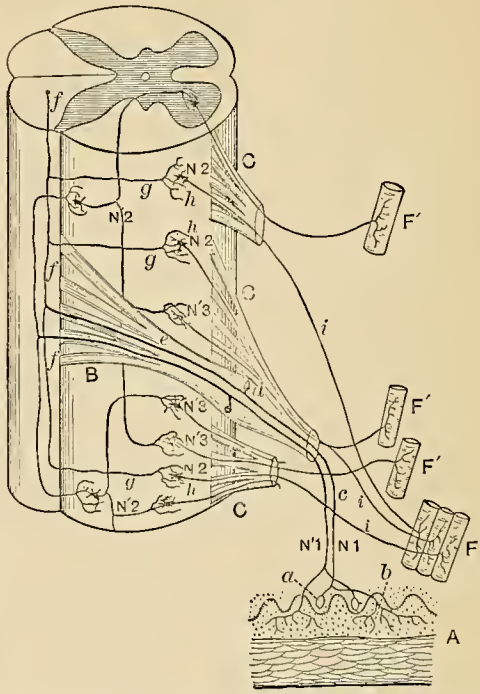

FIG. 27.—DIAGRAM TO ILLUSTRATE REFLEX ACTIONS.

A, skin; F, F', muscle fibres; large column at left represents a piece of the spinal cord with gray matter within and white matter without; B, dorsal nerve roots; C, ventral nerve roots; N 1, N' 1, N 2, N' 2, N 3, N' 3, neurons. A simple reflex path comprises N 1 and N 2, which include origin of axis-cylinder process in end bulb (*a*) or between cells (*b*), afferent fibre (*c*, *e*) belonging to cell body (*d*), branches (*f*) giving off "collateral" branches (*g*) to terminate about N 2; cell body (*h*), efferent fibre (*i*) terminating upon muscle fibre (F). A compound reflex path comprises a similar collecting neuron, N' 1, one or more correlating neurons, N' 2, and distributing neurons, N' 3. (Baker.)

In 1870 two German physiologists, Fritsch and Hitzig, found that if

the brain of a dog were exposed and the cortex stimulated in different places by electric shocks, contractions of the animal's muscles accompanied each stimulation, and the movements varied according to the particular cortical area that was touched.

Localization of Functions in the Cortex.

Since then investigation of the subject by various methods upon various animals and man has been active with the result that now localization of different functions in different parts of the cortex has become an accepted fact, although there is still considerable difference of opinion regarding the exact functions of different areas. The accompanying figures represent the opinions of authorities at present, but the details are subject to change by future investigation (Figs. 29 and 30). The most obvious principle regarding localization is that the motor area, which has the function of controlling through lower centres the actions of the various voluntary muscles, is situated in the middle part of the cortex, extending across the top of the brain; while the sensory area, which deals with the sensations arising from activity of the organs of the

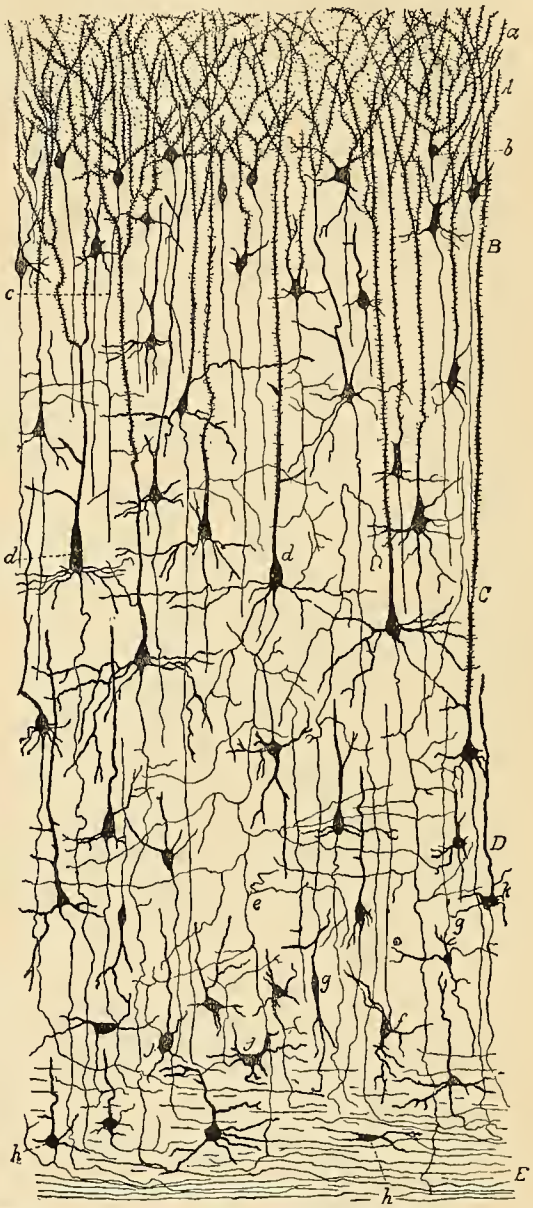

FIG. 28.—SECTION OF THE CEREBRAL CORTEX OF YOUNG MOUSE, SHOWING PSYCHIC CELLS AND THEIR BRANCHES.

A–D, various layers of cells; *E*, white matter; *a*, dendrites or protoplasmic processes; *c*, *e*, axis-cylinder processes; *b*, *d*, *f*, *g*, *h*, different types of cells. (Baker, after Ramón y Cajal.)

special senses and of the sensory nerves, lies farther back. The motor area lies in general on either side of the fissure of Rolando, and, as is

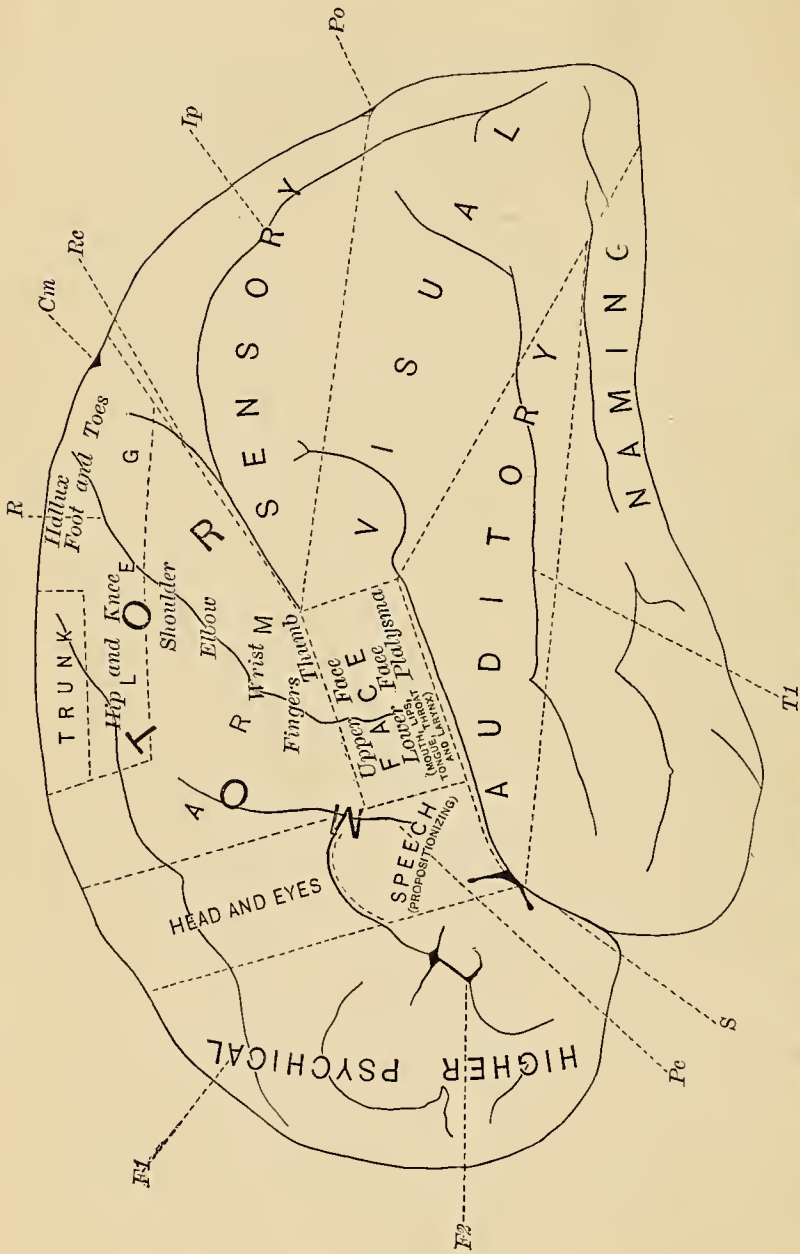

FIG. 29.—SIDE VIEW OF THE HUMAN BRAIN INTENDED TO SHOW THE POSITIONS OF VARIOUS NERVOUS CENTRES.
The area marked "motor" controls the movements of the designated parts of the body. The "sensory" area is believed to deal with sensations of touch. The "visual" area with sensations of sight, etc. Very little is known regarding the functions of the front parts of the brain, marked "higher psychical." (After C. K. Mills.)

seen in the figures, the centres for the actions of different groups of muscles have been localized. The centre marked speech is the motor

centre for the muscles of the organs of speech. In the living man it exists in the area a little behind and above the left temple. The

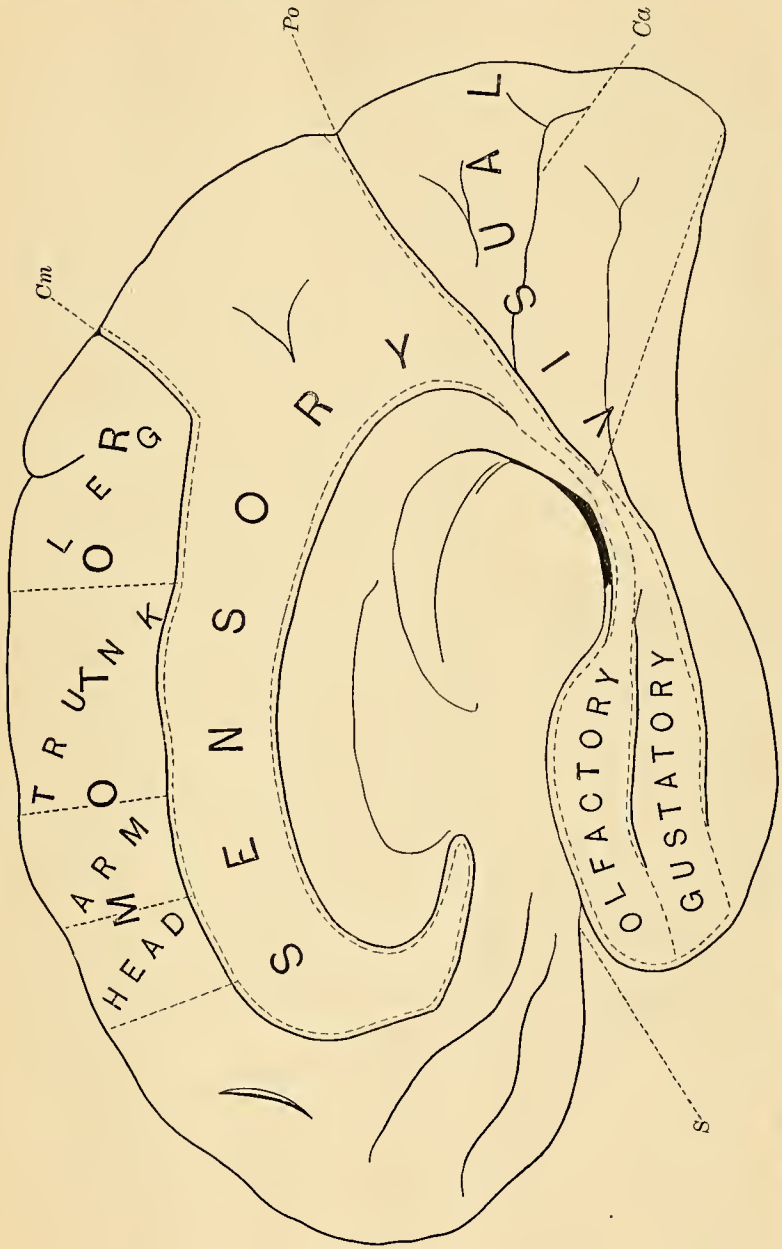

FIG. 30.—MEDIAN VIEW OF THE HUMAN BRAIN, INTENDED TO SHOW THE POSITIONS OF VARIOUS NERVOUS CENTRES NOT SHOWN IN FIG. 29. (After C. K. Mills.)

whole process of the understanding and the use of language is excessively complicated, involving many parts of the brain; a portion of

the nervous mechanism is represented in Fig. 31. Visual impulses (s'') from the printed words pass to the centre of sight (V); auditory impulses (a) from the spoken words pass to the centre of hearing (A); these centres are connected by "association" fibres with each other and with the motor centres for the arm, as used in writing (W), and for the vocal organs (E); when these muscles are employed, motor impulses (m', m) pass to them, while sensory impulses (s', s) inform the centres of what is going on. The various centres do not appear to be sharply marked off, but rather to overlap adjacent areas. Most of them exist upon both sides of the brain, and, as has been stated, each half of the brain controls the opposite side of the body. The right-handedness of most persons is due to the superiority and greater refinement of the left hemisphere of the brain over the right, and the reverse is true of left-handed individuals. Most persons are "left-brained speakers," since the speech centre is developed usually upon that side only.

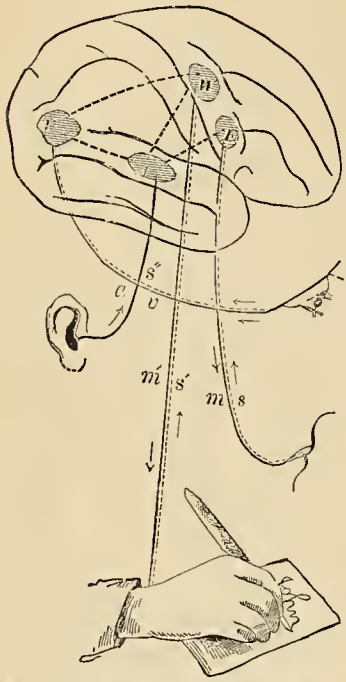

Fig. 31.—Diagram intended to show the nervous mechanism employed in the understanding and use of language (for description, see text). (James, after Ross.)

The functions of the frontal lobes of the cerebrum are quite unknown. The term "higher psychical," in Fig. 29, should be accepted with caution. We have not space here to go into a discussion of them, nor of the physical bases of the various psychical phenomena—the will, the feelings, attention, judgment, memory, etc. All such subjects are still in a very hypothetical stage.

Psychical Processes.

The modern doctrine of localization recalls the older school of phrenology and proves how utterly unscientific and unfounded were the phrenological conceptions. Where the phrenologist located "hope" the scientific physiologist finds the nervous mechanism of locomotion; "inhabitiveness" and "self-esteem" marked the centres now known to be concerned in vision. A bump upon the skull does not necessarily imply a bump upon the brain; and the laboratory work of Fritsch and Hitzig relegated phrenology to the inevitable oblivion of empiricism.

Phrenology.

In discussing the nervous system we have tacitly assumed that the function of any one part is simply to stimulate some other part to act.

Suppression or inhibition of action is, however, widespread, and of almost equal importance. The best-known example of inhibition is that of the vagus nerve slowing or stopping the beat of the heart. Every individual knows how often in his conscious life he is compelled to say "No" to his impulsive self, and an objective study of his own nervous processes, if such were possible, would show him that one of the frequent tasks of his nerve cells is to prevent or put a stop to the actions of other nerve cells. Probably any act of the individual beyond the very simplest is the result of a combination of motor and inhibitory nervous influences. Consider the nervous processes as portrayed in the accompanying figure (Fig. 32). The baby sees the candle flame for the first time and instinctively tries to grasp it; the nerve paths of this simple reflex action are shown in 1, 1, 1, 1, from the eye to the visual centre, thence to the motor centre and to the muscles that extend the hand. The finger is burned, and a second reflex results in the withdrawal of the hand; 2, 2, 2, 2, marks the reflex arc, from the sensory nerve endings in the skin to the sensory centre, thence to the motor centre and to the muscles that withdraw the hand. But the cerebral centres are apprised of the occurrences, and the upgoing impulses arouse perceptions of ($s1$) the image of the flame, ($m1$) the action of extension, ($s2$) the pain, and ($m2$) the action of withdrawal. The groups of cells mediating the perceptions are "associated" by fibres, and retain in their physical structure the "memory" of the events. A few days later seeing the candle arouses again the unconscious impulse to seize it. But the cortical cells are now on the alert, inhibitory impulses are shot down to the motor centres, and the hand is withheld.

Inhibition.

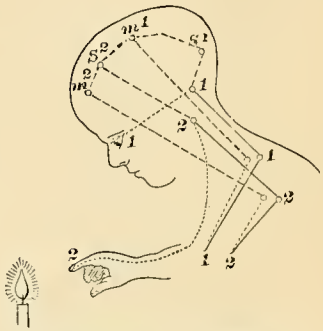

Fig. 32.—Diagram intended to show the paths of nervous impulses (for description, see text). (James.)

The nature of nervous impulses or nervous energy is not known. When nerve centres act, their protoplasm appears to undergo katabolic changes, to produce heat, to become fatigued, and thus to resemble other protoplasm in its general metabolic phenomena. Nerve fibres, however, are peculiar in that no evidences of katabolic changes are present in them during even long-continued passing of nerve impulses. The rate of transmission of impulses is not difficult to measure, and in man averages about one hundred feet in the second. A feeble electric current always accompanies the impulse, but the slow rate and other considerations seem to forbid the assumption that the impulse itself is electrical.

Nature of Nervous Energy.

During the past few years physiological psychologists have devoted much attention to the measurement of the time of cerebral processes—the time it takes to think. The basis of their investigations is the determination of the simple reaction time, which is the time that elapses between the giving of a stimulus—say sending an electric shock to the skin or light to the eye—and a signal made by the person to indicate that the stimulus is felt. The average reaction time—which, it is needless to say, varies greatly in different individuals—is between one tenth and two tenths of a second. It is shortest for touch, longest for sight, and for hearing it is intermediate between the other two (touch 0·14 seconds, hearing 0·16 seconds, sight 0·18 seconds). If the time required by the end organs and the nerves be subtracted from the whole interval between stimulation and reaction, there is left the time occupied by the brain itself in recognising the sensation and willing the motor response; this may be placed, in round numbers, at one tenth of a second. Practice and attention shorten the reaction time; fatigue and complication of the cerebral process (such as would be caused by offering the subject a choice between two kinds of stimulation) lengthen it.

Reaction Time.

CHAPTER IV.

SENSATION.

All parts of the body are supplied with sensory nerve fibres, and accordingly from all parts of the body impulses may go to the central nervous system and there give rise to sensations. Sensations are classified as either general or special. General sensations comprise those by which we recognise vaguely the existence and condition of the various parts of our bodies; bodily comfort and discomfort, fatigue and pain, are general sensations; all parts of the body seem to possess general sensibility. Special sensations comprise those that possess a more specific distinguishing quality than general sensations; they are mediated by specialized organs, which are confined to certain specific parts of the body. Formerly it was customary to recognise five classes of special sensations—namely, those of sight, hearing, taste, smell, and touch. Investigation has now shown that two others must be added to the list—namely, sensations of temperature and muscular sensations. The anatomical apparatus of each of the seven senses consists of (1) delicate end organs, which are adapted in each case to a special method of stimulation; (2) special afferent nerve fibres; (3)

Sensations in General.

special portions of the central nervous system which are the seat of the sensations. Of all the senses, sight has the most highly specialized organs, and may profitably be considered first.

Section I.

SIGHT.

The sense of sight arouses in us ideas of form, size, distance, light, shade, and colour. The end organs of sight are the eyes, which are adapted to stimulation by the vibrations of the ether that we call light; the afferent nerves are the optic nerves; and the seat of visual sensation is the cortex of the occipital lobes of the cerebrum.

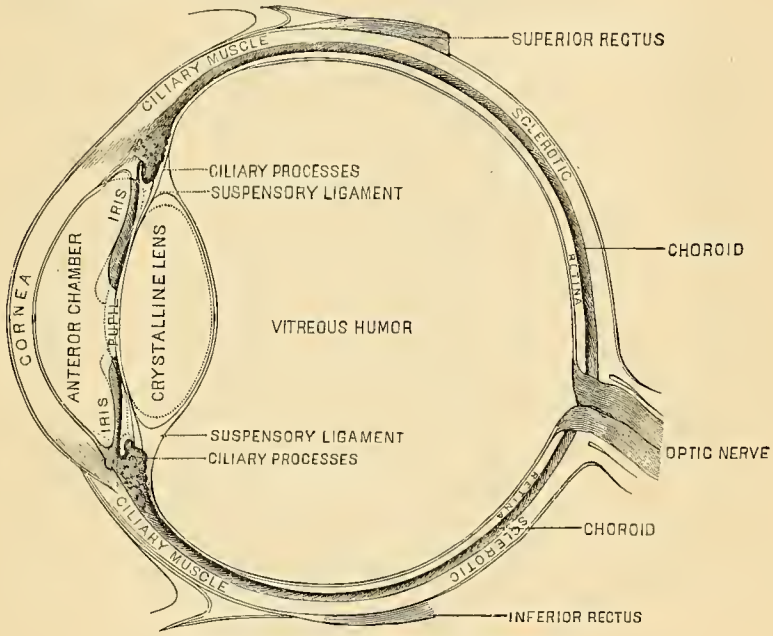

Fig. 33.—Section of the eyeball (Flint.)

Considered as a piece of physical apparatus, the eyeball is a camera obscura, of which the best-known example is the photographic camera—that is, it consists of a chamber with blackened walls. The back wall holds a sensitive plate, the *retina*, upon which an image of the object is thrown; the front wall is pierced by a hole, the *pupil*, about which is an adjustable diaphragm, the *iris;* and a system of transparent refractive bodies, or lenses, comprising the *aqueous humour*, the *crystalline lens*, and the *vitreous humour*, bring the rays of light to a focus upon the retina (Fig. 33). The

Physiological Anatomy of the Eye.

end to be reached is the stimulation of the nervous apparatus in the retina, and accordingly the retina is regarded as the essential part of the eye, all other parts being accessory.

Retina.

In its origin the retina is a part of the brain, which has grown out along the route of the optic nerve and has come to be located in the eyeball. It consists of nerve cells of different shapes, arranged in layers, as shown in the accompanying figures (Figs. 34 and 35), and bound together by supporting tissue. The significance of the various parts is not understood, but the terminal end

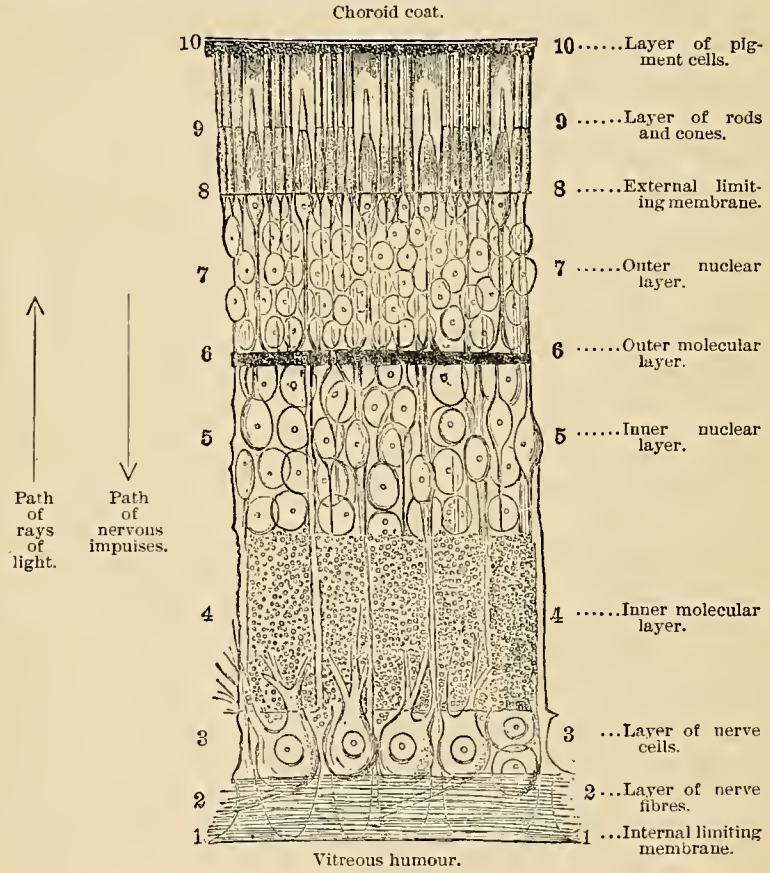

FIG. 34.—SECTION OF THE RETINA (DIAGRAMMATIC). (Schultze.)

organs of the nervous mechanism are the *rods* and the *cones*, which, through forming the outer layer of the retina, seem to be the parts that are sensitive to light, and upon which the image is focused. They consist of highly specialized protoplasm; their names and the figures indicate their shape. It is estimated that there are at least three million cones

and many more rods in each retina. The difference in function of the rods and the cones is not known. The light probably causes chemical changes in them, and thus originates nervous impulses; the latter traverse the various retinal layers of nerve cells and their processes, reach the optic nerve, and go thence to the brain. The retina may be stimulated mechanically by pressure upon the eyeball. Thus, rubbing the eyes, as is often done upon awaking from sleep, produces sensations of light in the form of points, spots, or circles. "Seeing stars," as the result of a blow, is due to mechanical stimulation of the retina.

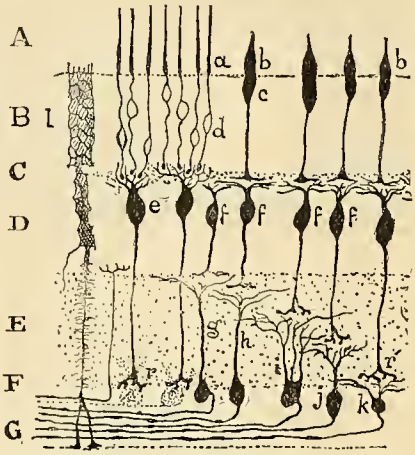

Fig. 35.—Section of the retina (diagrammatic), intended to illustrate the recent discoveries as to the structure and relations of the various layers.

A, layer of rods (*a*) and cones (*b*); *B*, outer nuclear layer; *c*, nucleus of cone; *d*, nucleus of rod; *C*, outer molecular layer; *D*, inner nuclear layer; *e*, rod-bipolar cell; *f*, cone-bipolar cell; *E*, inner molecular layer; *F*, layer of nerve cells; *g*, *h*, *i*, *j*, *k*, nerve cells with processes branching at different levels; *G*, layer of nerve fibres; *l*, non-nervous supporting cell (fibre of Müller). (Ramón y Cajal).

After-images.

The effect upon the retina lasts frequently for a considerable time after the eye is turned away from the object. For example, a single look at the sun will enable us to see suns for several seconds afterward. Such an after-effect is termed an *after-image*. Sometimes, and especially at first, it is of the same colour as the object, but later it appears in the opposite or complementary colour; in the former case it is called positive, in the latter negative. Thus the after-image of a white object may be at first white, but later it is gray or black; of a red object, perhaps momentarily red but soon green. Positive after-images are due to a continuation of the nervous excitation after the cause of it is removed; negative after-images result from fatigue of the nervous mechanism for the colour that is looked at, hence the predominance of the complementary colour.

Blind Spot.

The place of entrance of the optic nerve into the retina, being devoid of rods and cones, and, in fact, of all nervous organs except nerve fibres, is insensitive to light, and is called the *blind spot*. Its blindness may be proved by the following simple experiment: If the left eye be closed and the circular disk in Fig. 36 be looked at with the right eye, it will be found that the cross is also visible, except when the book is held at a distance of from nine to twelve inches from the face; at that distance the image of the cross falls upon the end of the optic nerve and is not perceived. In ordinary life each eye cor-

rects the invisible spot in the field of the other, and hence we do not appreciate the two gaps in our combined field of vision.

FIG. 36.—DIAGRAM FOR DEMONSTRATING EXISTENCE OF BLIND SPOT.

Formation of Retinal Image.

The formation of the retinal image is a purely physical matter, and follows the laws of refraction of light. The rays of light from each portion of the object looked at are bent out of their course by the three refractive bodies, but chiefly by the crystalline lens, and are brought to a focus upon the layer of rods and cones. Thus a small inverted image of the object appears upon the retina exactly as upon the ground glass of the photographic camera (Fig. 37). As in all optical instruments, focusing is necessary in order that the picture may be sharp and distinct. By the curvature of the lens and the length of the eyeball the eye is focused normally for objects situated at a great distance from the observer. For nearer objects focusing might be brought about theoretically either by making the lens more convex or by increasing the length of the eyeball. In the camera the latter method is employed by drawing back the plate of ground glass. In the eye the retina can not be moved, and hence the curvature of the lens is altered in the following manner: The lens is elastic, and normally is kept slightly flattened by the tension of surrounding parts. When vision is directed to near objects the ciliary muscle, which lies just outside the edge of the lens, contracts and pulls forward the choroid coat together with the suspensory ligament of the lens. Tension on the lens being thus diminished, the latter bulges forward and becomes more convex (Fig. 38). Sharpness of the image is also assisted by shutting out the rays that would come through the more external parts of the lens. This is accomplished by the muscular diaphragm, the iris, which, in proportion to the nearness of the object, contracts and

Accommodation.

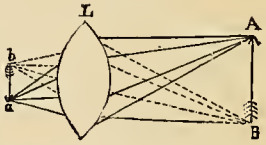

FIG. 37.—DIAGRAM ILLUSTRATING REFRACTION OF RAYS OF LIGHT AND FORMATION OF AN INVERTED IMAGE BY A LENS. *A B*, object; *L*, lens; *b a*, image. (Martin.)

diminishes the size of the pupil. Both the iris and the ciliary muscle are under nervous control, and their actions are delicately harmonized reflexly through the brain, the optic nerve being the afferent nerve.

Defects in Visual Apparatus.

Considered as an optical instrument, the human eye, although apparently so exactly adapted to its uses, is by no means perfect. Indeed, the distinguished German physicist and physiologist, Helmholtz, while admiring its surpassing fitness, once wrote of its shortcomings: "If an optician wanted to sell me an instrument which had all these defects, I should think myself quite justified in blaming his carelessness in the strongest terms, and giving him back his instrument." The eyeball may be too long (*near-sight*) or too short (*far-sight*); in both cases exact focusing for a wide range of vision is difficult, and, unless the eye is assisted by spectacle lenses, a blurred image falls upon the retina. The curvature of the front surface of the eyeball, the cornea, may be irregular, a very common defect known as *astigmatism*, which manifests itself also by a blurred image. The

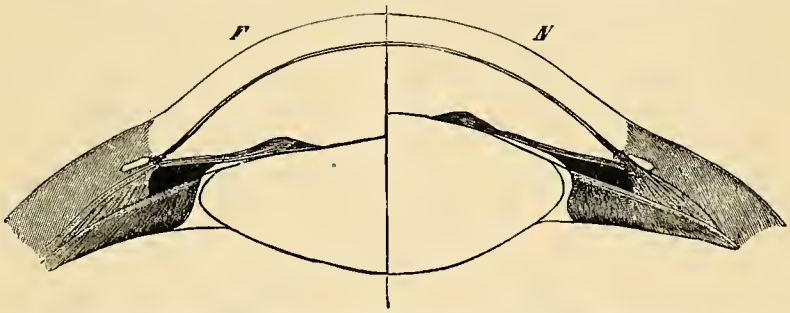

FIG. 38.—DIAGRAM ILLUSTRATING THE MECHANISM OF ACCOMMODATION OF THE EYE. In *N* the lens is accommodated for near objects; in *F*, for distant objects. (Fick.)

crystalline lens, like all lenses, produces some spherical and some chromatic aberration. Floating within the vitreous humour of all eyes are peculiar opaque particles, cells of irregular shape and filaments, that appear as mysterious moving particles in the field of vision; they are most evident when one gazes at a white wall or at the sky; they are entirely harmless. A considerable number of individuals suffer from colour blindness, which is apparently due to a lack of certain colour-perceiving elements in the retina and will be discussed hereafter. Lastly may be mentioned the trouble with vision that appears in most persons shortly after middle life (*old-sight*); it may be due to a weakening of the ciliary muscle or to a loss of elasticity of the crystalline lens.

The question as to how we see colour has been and still is the cause of much speculation, experimentation, and theorizing. Objectively one colour differs from another only in the length of the waves and the rapid-

ity of vibration of the ether; and white light is the resultant of a host of these different waves taking place simultaneously. By means of the spectroscope white light may be analyzed into seven colour groups, called "primary colours" viz.: red, orange, yellow, green, blue, indigo, and violet; and, since given these colours all colours whatsoever may be obtained by proper mixing, it follows that, if we can explain the perception of the primary colours, we can explain all colour vision. But the matter is simpler than this, for experiment shows that all colour sensations may be produced by proper mixing of three colours only instead of seven—*e. g.*, red, green, and violet. This fact is the basis of the common theory of colour vision, the Young-Helmholtz theory, which supposes the existence of three primary colour sensations, such as red, green, and violet, all other colour sensations being combinations of these. Perhaps these correspond to three kinds of material elements in the rods and cones or in other parts of the visual apparatus, each element being capable of stimulation by all colours of light, but more especially by one colour. Thus white light stimulates all three alike, red light the red-perceiving elements more strongly, and so on. Colour-blindness is due to a lack of at least one of the three kinds of elements—a red ribbon appears like a green ribbon because the red-perceiving elements are wanting. This theory accounts for many of the facts of colour vision, but is not entirely sufficient. Several other theories have been suggested and are being actively tested and discussed.

Colour Vision.

With some of the lower animals, such as the rabbit, every object is seen with one eye only; each eye has its own field of vision. Man, however, is a binocular animal, since under ordinary circumstances he directs his two eyes toward the object looked at. As a matter of fact, only the middle part of his field of vision is binocular, since the right eye alone sees to the extreme right, the left eye alone to the extreme left; the amount of overlapping of the right and the left fields in front depends upon the shape and the prominence of the nose. Slightly different pictures of the object looked at fall upon corresponding points in his two retinas, but out of the two images he receives a sensation of one object. Binocular vision is of the greatest value, since by it we are able to form much more exact ideas of distance, size, and form than by one eye alone. Binocular vision would be nearly valueless, however, were it not supplemented by the muscles of the eyeballs and their exact co-ordination by the central nervous system. These muscles rival those of the larynx in delicacy of action, and enable any point within the range of the two eyes to be turned to instantly. The newly born babe often possesses the primitive power of moving the eyes independently of each other, a power which adults rarely retain.

Binocular Vision.

Tears.

The eyelids exist for the protection of the eyeballs. Winking, by sweeping across the ball and through the lachrymal canals into the nose the secretion of the lachrymal gland, serves to keep the surface of the cornea moist, and to wash away foreign particles that might be injurious to it. When the secretion becomes excessive, it overflows in the form of tears. Lachrymal glands arose in the course of evolution, when aquatic animals gave rise to those leading a terrestrial life. Hence fishes, whose eyes are bathed constantly by the surrounding water, neither require nor possess them, while they exist in all animals above fishes. The power of weeping, although it has been observed in elephants, some monkeys, and in a few other animals, is confined chiefly to man. Usually, but not always, it signifies grief or bodily suffering. Darwin believes that it arose incidentally as the result of a chain of events somewhat as follows: The suffering child, like the young of other animals, cries out, partly for aid from its parents, partly to relieve itself by activity; in this act the blood-vessels of the eyes are gorged with blood, and to prevent injury therefrom the muscles about the eyes are contracted strongly (see Fig. 20, B); the muscular contraction causes in some reflex way not wholly understood a flow of tears from the gland; in the adult all the events in the chain are not necessary, and grief leads directly to weeping.

Section II.

HEARING.

Physiological Anatomy of the Ear.

The ear is the most complicated of all known sense organs. Its essential part comprises the nerve-endings in the membranous labyrinth of the internal ear; the accessory parts consist of the rest of the internal ear, the middle ear, and the external ear. In so far as the ear is used for hearing, it is adapted to receive the vibrations of air that we call sound and to transmit them to the nerve terminations. The diagram (Fig. 39) shows the relations of the various parts of the auditory organ. The pinna, or external part that we commonly call the ear, is omitted from the figure, but the passage (*E. M.*, *external auditory meatus*) is shown, and the arrow indicates the path of the waves of sound. The waves cause the tympanic membrane (*Ty. M.*) to vibrate, and this produces a gross movement of the delicate ear bones (*Mall.*, *Inc.*, *Stp.*) that stretch across the air-space of the middle ear (*Ty.*). The middle ear is seen to be really a drum with one drumhead (*Ty. M.*) upon one side, two drumheads (*F. o.*, *F. r.*) upon the opposite side, and a passage (*Eu.*) to the pharynx, and thus to the outside air, for the purpose, as in all drums, of equalizing

the pressure of air within and without. Through the membrane of the *fenestra ovalis* (*F. o.*) the liquid perilymph within the bony labyrinth (*Sca. V.*, *Sca. T.*) of the internal ear is set into vibration. The vibrations pass through the walls of the membranous labyrinth, affect the liquid endolymph, and stimulate the nerve-endings (*Sca. M.*). A more detailed but still diagrammatic figure of the membranous labyrinth is shown in Fig. 40. It is there seen that the labyrinth consists of three distinctive parts, viz.: two central irregular-shaped cavities (*utricle* and *saccule*) indirectly connected; three *semicircular canals* joining the utricle, each with an enlargement, the *ampulla*; and the *canal of the cochlea* (*Coch.*), joining the saccule. Each of the three distinctive parts contains in its walls characteristic nerve terminations; and, as the figure shows, there are in reality six end-organs within the ear. Of these it is probable that the nervous organ in the cochlea alone, the organ of Corti, is auditory in function.

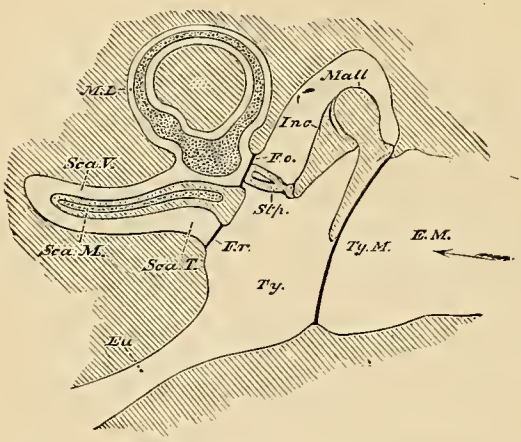

FIG. 39.—DIAGRAM OF EAR.

The external ear comprises the external projecting part, or *pinna* (omitted from figure), and the *external auditory meatus* (*E. M.*); the arrow indicates the direction of the waves of sound. The middle ear or *tympanum* (*Ty.*) comprises the *tympanic membrane* (*Ty. M.*), the *fenestra ovalis* (*F. o.*), the *fenestra rotunda* (*F. r.*), the three bones, *malleus* (*Mall.*), *incus* (*Inc.*), and *stapes* (*Stp.*), and the Eustachian tube (*Eu.*); the middle ear is filled with air, and connects with the pharynx through *Eu.* The internal ear, or *labyrinth*, comprises the osseous labyrinth and the membranous labyrinth. Both are highly diagrammatic in figure, the former being reduced to *scala tympani* (*Sca. T.*) and *scala vestibuli* (*Sca. V.*) of cochlea, and one *semicircular canal*, the latter being reduced to *scala media* (*Sca. M.*) of cochlea, and one *semicircular canal* (*M. L.*); the osseous labyrinth is filled with perilymph, the membranous labyrinth with endolymph. All bony parts are shaded with oblique lines. (Huxley.)

Organ of Corti.

The organ of Corti (Fig. 41) is a complex mechanism, resting upon one wall of the cochlear canal, the *basilar membrane*, and extending from the base to the apex of the cochlea. It consists of a succession of curious rodlike structures, the rods of Corti, beside which are columnar cells, tipped with hairs and surrounded by the terminations of the nerve fibres; the hairs pass through a perforated membrane (*reticulate membrane*), and over all is a curtain, the *tectorial membrane*. The hair-cells are the proper end-organs; they correspond in function to the rods and cones of the retina; through them the nerve fibres are stimulated. But the method of stimulation has not yet

been satisfactorily determined. It will be remembered that the organ of Corti is bathed with endolymph and the bony labyrinth outside the cochlear canal is filled with perilymph, hence the vibrations caused by sound may be transmitted readily to the organ of Corti. It was formerly thought that the rods of Corti first received these vibrations, and that from them the nerves were stimulated. But it seems more reasonable to believe that the important part of the organ is the basilar membrane, which consists of parallel fibres extending from within outward, and which may act somewhat after the manner of the wire board of a piano.

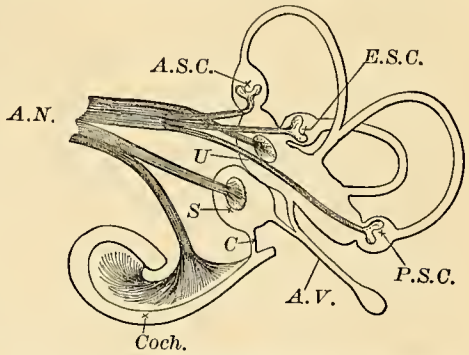

FIG. 40.—DIAGRAM OF MEMBRANOUS LABYRINTH AND DISTRIBUTION OF AUDITORY NERVE.

U, utricle; *A. S. C.*, *E. S. C.*, and *P. S. C.*, anterior, external, and posterior semicircular canals; *A. V.*, aquæductus vestibuli; *S.*, saccule; *C.*, canalis reuniens; *Coch.*, canal of cochlea, or scala media; *A. N.*, auditory nerve, dividing into six branches that end respectively in the three *cristæ acusticæ* of the ampullæ of the semicircular canals, the two *maculæ acusticæ* of the utricle and the saccule, and the organ of Corti in the cochlea. (Huxley.)

In discussing voice we spoke of pitch, quality, and loudness as three characteristics, the production of which was to be explained. A theory of hearing must explain the recognition of these three characteristics. According to the theory now usually adopted, the recognition of pitch depends upon

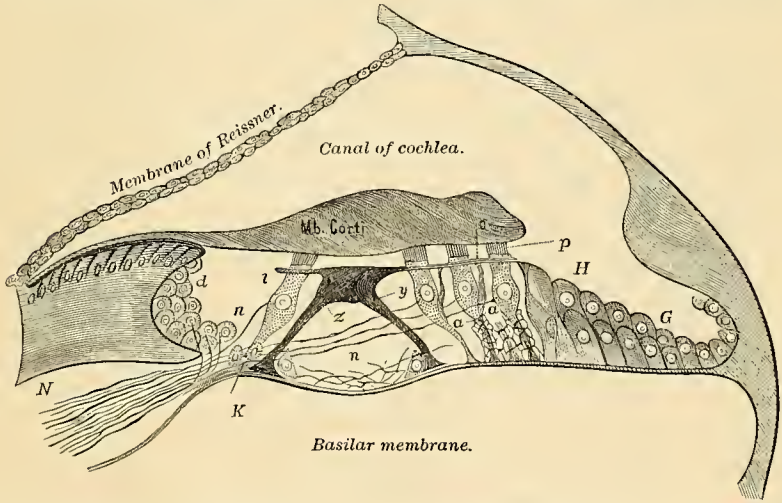

FIG. 41.—DIAGRAM OF CROSS-SECTION OF CANAL OF COCHLEA, SHOWING ORGAN OF CORTI RESTING UPON BASILAR MEMBRANE.

z, inner, and *y*, outer rod of Corti: *i*, inner, and *p*, outer hair cells; *N*, nerve, and *n*, nerve fibrils passing to hair cells; *o*, reticulate membrane: *Mb. Corti*, membrane of Corti, or tectorial membrane; *d*, *K*, *a*, *H*, *G*, epithelial cells. (Landois.)

the particular part of the basilar membrane that is put into vibration. The fibres of which the membrane is composed, about twenty-four thousand in number, become increasingly longer from the base to the apex of the cochlea. It is conceivable that, just as is the case in the piano, the longer fibres vibrate to the lower notes only, the shorter fibres to the higher notes only; and with each note the hair-cells that rest upon that portion of the membrane and their contiguous nerve fibres are stimulated. Quality of sound depends upon the number and prominence of the overtones that accompany the fundamental tone. When a piano-key is struck and a single wire is put into vibration, other wires vibrate in unison and produce overtones. So in the basilar membrane of the ear, when one part vibrates other parts vibrate, and nervous impulses are produced corresponding to the fundamental tone and the overtones of the sound that comes to the ear. Recognition of loudness depends upon the extent of vibration of the basilar membrane. Therefore, according to the theory of the all-importance of the basilar membrane in hearing, a sound after coming to the ear and reaching the membranous labyrinth is analyzed into its constituent vibrations. Nervous impulses corresponding to the various vibrations are produced in the fibres of the auditory nerve, are transmitted to the brain, and give rise to sensations. These various sensations are combined and elaborated into a perception of the sound. It should be said that this theory is not wholly satisfactory.

Recognition of Pitch, Quality, and Loudness.

The semicircular canals and their nervous end-organs, the *cristæ acusticæ*, seem to have nothing whatever to do with hearing. They are sense-organs of bodily equilibrium; they enable the individual to recognise the turning of the head and of the body out of one position into another. They are especially prominent in fishes and in birds—animals that spend much of their time in diving and turning in fluid media, the water and the air respectively. In each ear the planes of the three canals are nearly at right angles to each other, so that they represent the three planes in space. Each canal is hollow and filled with endolymph, and its *crista acustica*, which lies in the enlarged ampulla, seems specially adapted to stimulation by movement of the contained liquid (Fig. 42). The cells about which the nerve-fibres terminate are tipped with long hairs that project into and float in the endolymph. Any curved movement of the head in or approximately in the plane of a canal may readily cause a bending of the hairs and a stimulation of the nerves. If a movement of the head takes place in any other plane, two or more canals may be stimulated at once, and by means of the six canals of the two ears acting in various combinations curved movements in all possible planes in space

Semicircular Canals.

may be appreciated. Roughly speaking, the canals act as spirit levels, and the delicacy of their action is realized when we consider with what accuracy we can detect the slightest turning of the body out of equilibrium.

Saccule and Utricle.

Whether the saccule and the utricle are auditory in function is in great doubt. It was once believed that their nervous terminations appreciate noises as distinct from musical sounds, which stimulate the cochlear organs. But it now seems probable that the cochlea deals with both kinds of sounds. Structurally the *maculæ acusticæ*, the two nervous end-organs upon the walls of the saccule and the utricle, are similar to the cristæ of the semicircular canals; the hairs are shorter, however, and lying upon and among them is a mass of calcareous crystals, the *otoliths*. Experiments upon fishes make it practically certain that these organs appreciate the position of the head, and thus of the body, in space, and hence are organs of equilibrium of the body when at rest. The mode of stimulation is believed to be by the constant pressure of the otoliths upon the hair-cells, and the production thus of a constant nervous impulse that gives the individual an idea of his position; if the body be thrown out of the normal attitude, the pressure of the otoliths is altered, and thus the individual recognises his new position. Experiments upon fishes indicate also that the saccule and the utricle appreciate simple progressive bodily movements in a straight line. It seems not unreasonable to suppose that these parts may have in man the same functions as in the lower animals. If this be so, the semicircular canals, the saccule, and the utricle act together and form a most efficient organ of equilibrium for the body in all possible movements and in all possible positions. It is an interesting but unsolved problem as to how the organ of equilibrium and the organ of hearing became associated with each other in the ear.

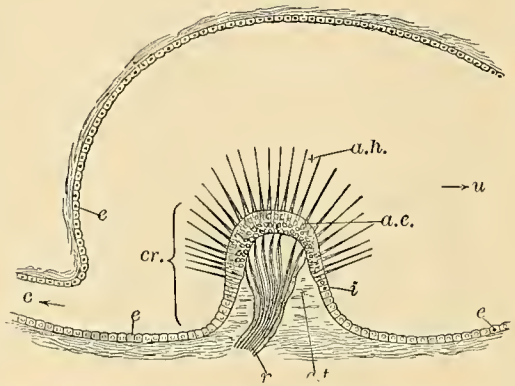

FIG. 42.—DIAGRAM OF LONGITUDINAL SECTION OF AMPULLA OF SEMICIRCULAR CANAL, SHOWING CRISTA ACUSTICA (*cr.*)

c, opening into canal; *n*, opening into utricle; *e*, epithelial lining of ampulla; *n*, branch of auditory nerve supplying crista; *a. e.*, hair cells; *a. h.*, hairs projecting into endolymph; *c. t.*, connective tissue. (Huxley.)

Section III.

SMELL. TASTE.

Different animals vary greatly as to the relative importance of their various sensations. The world is made known to man, for example, chiefly through sight, hearing, and touch. The dog's world is largely a world of odours, and in him the sense of smell, comparatively unimportant in man, is very acute. A substance, in order to be smelled, must be either in a gaseous or in a very finely divided condition. The organs of smell comprise the upper portion of the two cavities of the nose; the lower portion serves as a passageway for air in respiration; hence in quiet respiration odours are not usually perceived; they come into consciousness only when they are very strong or when by sniffing the air containing them is forcibly drawn up to the olfactory organs. The organs are very simple, consisting solely of the membrane lining that portion of the nasal cavities (Figs. 43, 44). The membrane is composed of columnar epithelium cells, and contains glands that, together with the cells, secrete the mucus with which the nose is always moistened. Among the cells are scattered long delicate ones that resemble somewhat the rods of the retina, and from which nerve-fibres go directly to the

Smell.

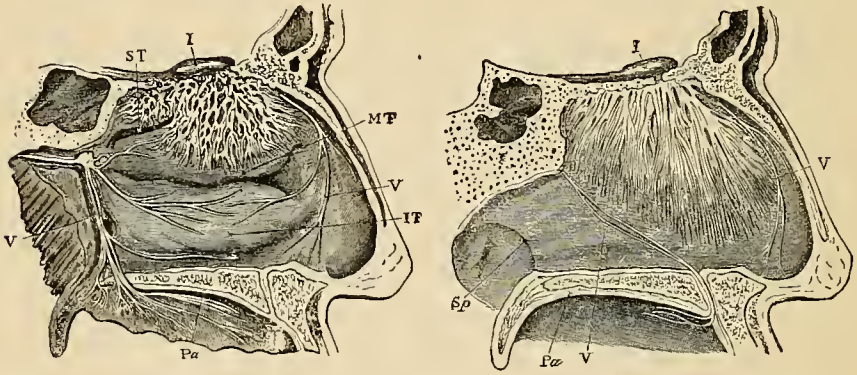

Fig. 43. Fig. 44.

Figs. 43 and 44.—Vertical longitudinal sections of the cavity of the nose.

Fig. 43 represents the outer wall of the left nasal cavity; Fig. 44 the inner wall of the right nasal cavity. *ST*, *MT*, *IT*, superior, middle, and inferior turbinate bones; *Pa*, hard palate separating nasal cavity from mouth; *Sp*, septum or partition between the two nasal cavities; *I*, lies within the brain cavity, and points to the olfactory nerve, with its numerous branches; *V*, branches of the trigeminus or fifth nerve. (Huxley.)

brain (Fig. 45). These are the *olfactory* cells, and they are stimulated by the odoriferous substance coming in contact with their exposed ends. The amount of substance needed to cause a sensation of smell is incon-

ceivably small; it is said that ·000000005 of a milligramme of oil of peppermint suffices. No satisfactory classification of odours has yet been made, analogous to that of colours in light and pitch in sound.

The sense of taste, like the sense of smell, is relatively unimportant in man. In many respects it is not unlike the sense of smell. The organs of taste comprise certain portions of the lining membrane of the mouth cavity—viz., the surface of the tongue, the soft palate, and the columns upon either side at the back of the mouth (anterior pillars of the fauces). Situated in the covering of these parts of the tongue, upon some of the papillæ that roughen its surface, are small groups of sensory cells, called *taste-buds* (Fig. 46). The *gustatory* cells composing them are not unlike the olfactory cells in appearance. They are sunk a little below the surface, their exposed ends being reached through a small pore. They are stimulated, like the olfactory cells, by a minute quantity of the substance that is to be tasted coming to them in solution. It is possible that there exist other organs of taste whose function is as yet undiscovered.

Organs of Taste.

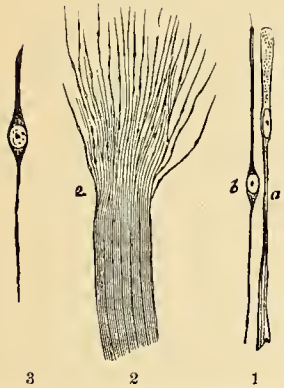

Fig. 45.—Nerve and end-organs of sense of smell.

1, cells from nasal cavity of frog; *a*, epithelial cell; *b*, olfactory cell; 2, branch of olfactory nerve of frog, terminating in fibrils; 3, olfactory cell of sheep. (Kölliker.)

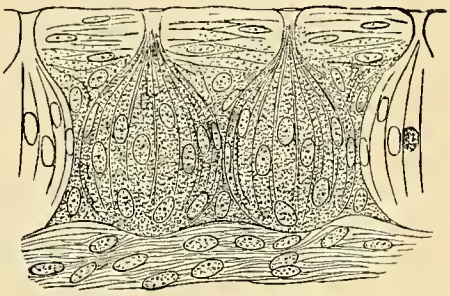

Fig. 46.—Two taste-buds from the rabbit's tongue. (Magnified 450 diameters.) (Engelmann.)

Like colours in light and pitch in sound, four classes of tastes are recognised, viz., sweet, sour, bitter, and salty; and probably all tastes not precisely these are combinations of them. Each of these classes probably has its own end-organs and nerve-fibres. The front part of the tongue tastes sweet and sour substances, the back part bitter substances. Some substances, like a certain compound of saccharin, when placed upon the tip of the tongue taste sweet, upon the back of the tongue bitter, because they are able to stimulate both kinds of end-organs. Taste is assisted greatly by smell, the two senses usually working intimately together. This may readily be proved by the easy experiment of holding the nose, closing the eyes, and then

Classes of Tastes.

endeavouring to distinguish by taste alone between a bit of apple and a bit of onion, or between a particle of banana and a strawberry.

Section IV.

TOUCH. TEMPERATURE. MUSCULAR SENSE. GENERAL SENSIBILITY.

By the term "sense of touch" is now meant the sense of pressure. Its organs are localized in the skin, and consist probably of various known forms of *touch corpuscles.* These are minute spherical or ovoid bodies, consisting of cells among which nerve-fibres end, the structure indicating that their natural method of stimulation is by pressure upon the skin overlying them. Recently, physiologists have succeeded in mapping out the surface of the skin into "pressure points," which recognise the touch of bodies applied to the skin, and minute areas between them, which are wholly devoid of the sense of touch. The "pressure points" probably overlie the organs of touch. The forehead and the back of the hand seem to be among the most sensitive parts of the skin, recognising a weight of $\frac{1}{30}$ of a grain, but the tips of the fingers can distinguish more exactly two objects placed near together.

Touch.

The sense of temperature, also localized in the skin, has only recently been recognised as a sense distinct from that of touch. It comprises, in reality, two senses, that of warmth and that of cold, which are now believed to be so far distinct as to have separate end-organs and separate nerves. Just as with the sense of pressure, so with temperature, it has been found possible to map out the surface of the skin into points that recognise only warmth ("warm spots") and points that recognise only cold ("cold spots"). The warm spots are distinct from the cold spots, and both are distinct from the pressure points. There exist in the skin various sensory organs, besides the touch corpuscles, and it is believed that some of these mediate sensations of temperature, but it is not yet decided as to which are organs of warmth and which organs of cold. The face is the region of the skin most sensitive to temperature.

Temperature.

By muscular sensation we recognise the amount of contraction that a muscle is undergoing; and from such data we form judgments of the size, form, position, and weight of objects. Since muscular contractions occupy so large a field in our daily life, the muscular sense is important. The existence of a muscular sense can be indicated by a simple experiment: If an object be held in the hand and be moved up and down, we have a distinct consciousness of the

Muscular Sense.

tension exerted upon the muscles of the arm; from this muscular feeling we can form a much more accurate estimate of the weight of the object than from the feeling of pressure of the object upon the skin of the hand; the feeling of pressure distinct from that of muscular contraction can be studied by laying the hand flat upon the table and placing the object in the palm. What the sensory end-organs are that mediate the muscular sense is not known; nor is it known whether they are localized in the muscles themselves, in their tendons, or in the joints. There is evidence in favour of each of these three localities.

Touch, Temperature, and Muscular Sense rarely separated.

Although sensations of touch, temperature, and muscular contraction are regarded as distinct and as mediated by three kinds of end-organs, nerves, and brain-centres, as a matter of fact we rarely use one of these senses by itself. They are inextricably bound together in ordinary life. Especially are our judgments of the characteristics of objects that are touched by our hands formed from a mixture of these three kinds of sensations.

Common Sensation.

General sensibility has been referred to as the property by which we recognise, in a vague way, the existence and the condition of the various parts of our bodies. The sensations of pain, fatigue, hunger, thirst, shivering, tickling, nausea, general bodily comfort and discomfort, have all been referred to general sensibility. Since many of these sensations enter largely into our everyday life, it seems strange that we have but little exact anatomical or physiological knowledge regarding them. Future investigation may possibly succeed in lifting some of them out of the ill-defined group of common sensations into new special senses. Pain is now commonly believed to be due to excessive stimulation of nerves of general sensation, and thus to have a nervous mechanism distinct from those of the seven senses.

CHAPTER V.

REPRODUCTION.

Reproduction in General.

The functions so far considered have reference to the daily life, well-being, and preservation of the individual man or woman. But the human being has, in common with other organisms, the instincts of racial continuance, and racial continuance is assured only by the production of new individuals. In the simplest one-celled organisms all individuals are alike, and reproduction takes place by a simple splitting of the individual body into two

bodies. In many-celled organisms sexes exist, individuals are either male or female, and reproduction is more complicated. The essence of sexual reproduction consists in the production by the two sexes of germ-cells (the *ovum*, or egg, by the female, and the *spermatozoön* by the male), the union of these two germ-cells, and the growth therefrom of the new individual. The reproductive organs subserve these three functions. For the structure and relations of the organs the reader is referred to the article on *The Anatomy of the Human Body.*

Egg.

The human egg (Fig. 47) is a soft, delicate, spherical cell, about $\frac{1}{125}$ of an inch in diameter. It consists of protoplasm and a small quantity of food substance scattered through it. In the egg of the fowl, the egg most familiar to us, the vital part corresponding to the human ovum is in the small whitish spot upon one side of the yolk. To this is added, for the nourishment of the growing chick, the rich food-substance of the yolk and the white, while the shell

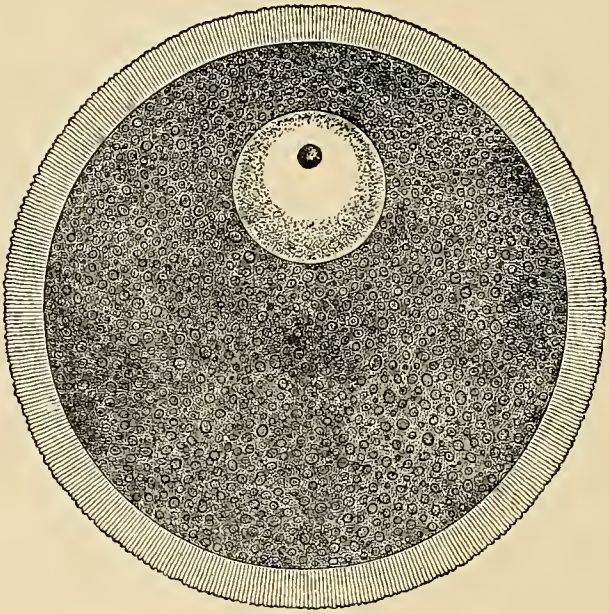

FIG. 47.—A HUMAN EGG MUCH ENLARGED.

The greater part of the egg consists of finely granular living protoplasm and coarsely granular lifeless yolk, the two being intimately mingled together. Toward the upper part of the figure lies the spherical *germinal vesicle* or nucleus, within which is the small, denser (dark) *germinal spot* or nucleolus. The egg is surrounded by a thick, transparent egg-membrane, or *zona pellucida*, which is penetrated by fine pore-canals, represented by radiating lines. (Haeckel.)

is a protective covering. The human chick develops within the body of the mother, hence a mass of food within the egg and a shell are unnecessary. Eggs are produced within the ovary of the mother (Fig. 48)

throughout the period of her sexual life—*i. e.*, from puberty, at the age of thirteen to seventeen, until the menopause, at forty to fifty years

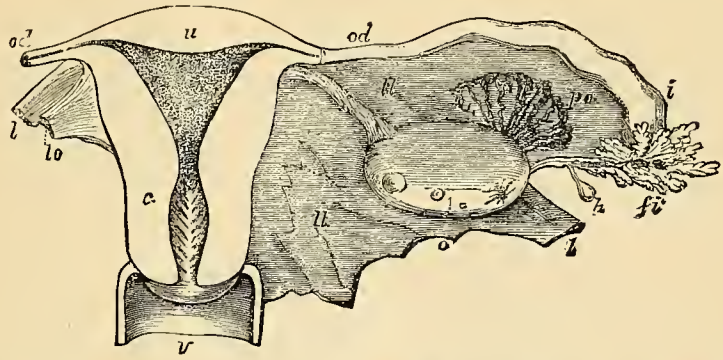

Fig. 48.—Female reproductive organs (two thirds the natural size), as seen from behind.

u, upper part, and *c*, neck of uterus (in section); *v*, upper part of vagina; *od*, Fallopian tubes (left one cut off) opening into cavity of abdomen at *fi*; *o*, right ovary; *po*, *h*, accessory ovarian structures; *l*, *ll*, *lo*, supporting ligaments.

of age. During this period, at intervals of about twenty-eight days, unless interrupted by pregnancy or disorders, an ovum becomes ripe, breaks through the ovarian wall, and is discharged from the body through the Fallopian tubes, the uterus, and the vagina.

Accompanying this discharge characteristic phenomena take place in the wall of the uterus and elsewhere, constituting *menstruation*. The lining membrane of the uterus, which has become thick and swollen with blood, rapidly degenerates, breaks away from its attachment, and gradually passes away from the body through the vagina, accompanied by a considerable flow of blood from the torn blood-vessels of the uterine wall, and by mucus. The menstrual flow occupies upon an average about four days. It is preceded by a general increase in physiological activity and excitability, by a rapid pulse and a high temperature, and is accompanied by more or less profound bodily and mental alterations, lassitude, and general vital depression. The significance of this curious monthly cycle, which is an inheritance from our mammalian ancestry, and which finds its counterpart in the "heat" of animals and the actual menstrual flow of the female monkey, is a disputed question. As has been said, menstruation is accompanied by the discharge of an ovum, and there is no reason to doubt that there is an important relation between the two phenomena, and probably between menstruation and pregnancy. According to one prominent theory, the tearing loose of the lining of the uterine wall is for the purpose of providing a fresh surface to which the ovum, if impregnated in its passage outward, can readily attach itself and there develop. An antagonistic

Menstruation.

theory supposes the thickened uterine membrane to act as such a bed for the ovum, and the shedding of the membrane to be a sign that the ovum has not attached itself. Menstruation does not usually occur during pregnancy or nursing.

Spermatozoön.

The spermatozoön (Fig. 49) is a curiously modified cell, consisting of a flattened, egg-shaped head, a short, rodlike middle piece, and a long, slender, delicately tapering tail. Its length is from $\frac{1}{400}$ to $\frac{1}{500}$ of an inch. The tail is a locomotor organ solely, and is capable of very active lashing movements, which are sufficiently powerful to propel the whole spermatozoön, when placed in liquid or upon a moist membrane. This is essential to insure the meeting of the two germ-cells. The spermatozoa are produced in the testis along with some liquid; the mixture, together with liquid secreted by other glands connected with the generative passages, constituting a thick, whitish fluid, the *semen*. The semen is produced from puberty until old age, and is stored in the testis, in its duct, and in the seminal vesicles.

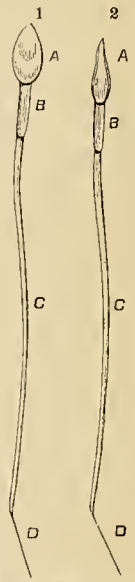

Fig. 49.—Human spermatozoa. (Magnified 600 diameters.)
1, flat view; 2, side view. *A*, head; *B*, middle piece; *C*, tail; *D*, terminal filament. (From Flint, after Landois.)

Fertilization.

During sexual union the seminal fluid is transferred from the body of the male to the vagina of the female, whence the spermatozoa make their way by their own movements through the uterus and along the Fallopian tubes. Here they may live for several days awaiting the discharge of an ovum. If the egg appears, one spermatozoön bores its way into it, the tail being left outside to die. The head of the spermatozoön and the ovum fuse together, the process being called fertilization, and the development of the new being is then ready to begin. Thus it is seen that every individual begins his life as a single minute cell within the body of the mother, which cell consists of material substance derived partly from the body of the father, partly from that of the mother.

Growth.

The phenomena of embryonic growth that follow fertilization are probably the most remarkable of all vital phenomena, and are of surpassing interest. The impregnated ovum divides into two cells, each of the two into two, making four cells, the four into eight, the eight into sixteen, and so on (Fig. 50), this process being called segmentation. At the same time the segmenting egg passes along the Fallopian tube and enters the *uterus*, or *womb*, which for the subsequent nine months is to be the home of the future human being. The egg attaches itself firmly to the uterine wall and becomes embedded in and

covered over by its lining membrane, which in the meantime has become congested with blood, and has grown rapidly, as before menstrua-

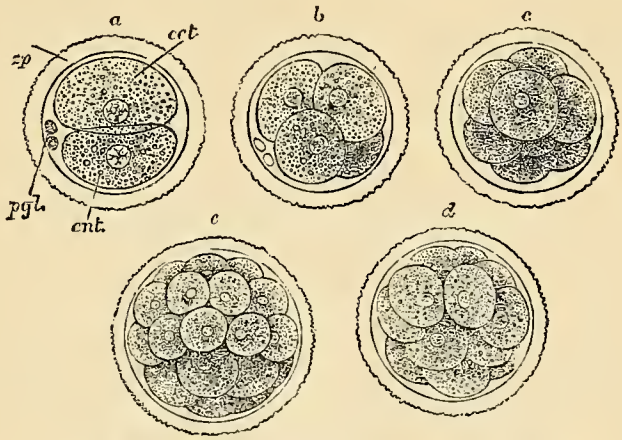

FIG. 50.—SEGMENTATION OF THE EGG OF THE RABBIT.

a, two-celled stage: *b*, four-celled stage; *c*, eight-celled stage; *d*, *e*, further stages; *ect*, cell destined to give rise to *ectoderm*, or outer layer of embryonic cells: *ent*, cell destined to give rise to *endoderm*, or inner cells; *zp*, zona pellucida; *pgl*, polar globules, or cast-off bits of nucleus. (Much magnified.)

tion. The number of cells in the young and delicate embryo increases; the cells become differentiated in size, shape, and function, and form the tissues and the organs. The embryonic heart begins to beat, by degrees the human form is evolved, and the child is gradually prepared for its entrance into the world.

Into the details of embryonic growth we can not here go. One point we may refer to—that is, the anatomical and physiological connection that exists between the infant and the mother.

Placenta.

The embryo, surrounded by fluid and by membranes, develops within a cavity in the wall of the womb, and by its continued growth and increase in size the original cavity of the womb becomes practically obliterated (Fig. 51). The embryo, however, is free from actual attachment to the maternal tissues except at one point—the navel of the child is connected by the umbilical cord (Fig. 51) to a considerable area of the uterine wall, the attachment being the *placenta*. The placenta is the embryonic organ of nutrition—food reception, respiration, and excretion. The embryo, inclosed as it is, is incapable of using its alimentary canal, lungs, and organs of excretion, and hence all its income and outgo must be carried on between its own blood and that of its mother. The blood and the blood-vessels of the two are quite distinct from each other; the child has its own intrinsic blood system. But in addition to this the large umbilical artery passes from its body along the umbilical cord, there to end in the placenta in thin-walled

tufts that penetrate into large spaces filled with the mother's blood. The embryonic and the maternal blood are separated by a thin membrane only, that allows ready diffusion of food, oxygen, carbonic acid, and wastes. The embryonic blood is purified and refreshed at the ex-

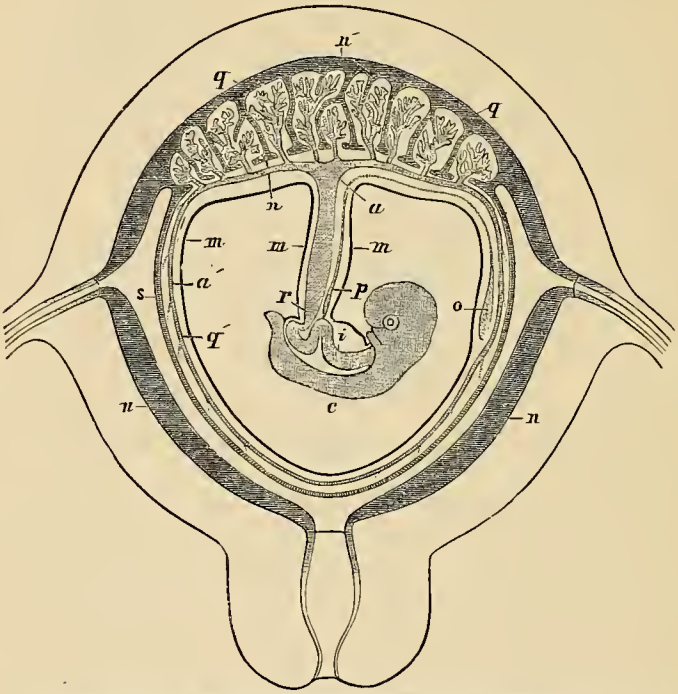

FIG. 51.—EMBRYO WITHIN THE UTERUS. (Diagrammatic.)
c, embryo; *i*, alimentary canal of embryo; *r*, *p*, *m*, *m*, various structures composing the umbilical cord; *q*, *n'*, *q*, *a*, placenta; *m*, *a'*, *q'*, *s*, membranes surrounding embryo; *n*, *n*, lining membrane of uterus: at each side extends off a Fallopian tube, and below is the neck of the uterus. (Liégeois.)

pense of the mother, and is returned by the umbilical vein to the body of the child.

The usual duration of pregnancy is about forty weeks. Toward its close the presence of rhythmically repeated pains in the uterus heralds the birth of the child. These pains of labour are accompaniments of wavelike contractions that pass over the muscular uterine walls. With each succeeding contraction the walls press closer and closer upon the fœtus, the opening of the womb and the vagina relax, and the child is slowly and painfully forced upon the world. The first breath is drawn into the lungs, and the infant announces its arrival by cries of distress. The umbilical cord is tied and cut; a few minutes after birth the placenta is expelled; and after this the wounded uterus gradually heals.

Birth.

Usually for some time after birth the child continues to depend upon the mother for its sustenance. During pregnancy the mammary glands of the mother, which form the breasts, increase in size and in functional power, and at the time of birth they are capable of secreting the milk that the child requires. Human milk is essentially not unlike the milk of other female animals. It contains, however, somewhat more sugar, and is more watery than cow's milk.

Milk.

We can not bring this chapter to a close more fittingly than by a brief review of the physiological life of the individual and a reference to some of its more special features. A lifetime may be divided roughly into three periods: those of youth, of middle life, and of old age. Youth is the period of growth, middle life that of maturity, and old age that of decline. A sharp distinction between these three is, however, impossible: the coming of age of the individual at twenty-one years is a convenient legal fact, but not a principle of nature. Growth in height may continue until about twenty-five years of age, and after fifty years a diminution of stature may follow. Weight may continue to increase until forty years, and after sixty years it may decrease. From about ten to fifteen years of age girls grow more rapidly than boys, the year of most active growth in girls being, in Europe and the United States, the thirteenth. After the fifteenth year boys surpass girls in rate of growth, their most active year being the sixteenth. Girls reach puberty before boys, and attain their complete growth at an age three or four years younger than boys. The metabolism during the period of youth is of necessity largely constructive, during middle life the constructive and destructive phases balance each other, and in old age destructive metabolism, with possible fatty or calcareous degeneration of tissues, becomes more prominent. In comparison with the young of most other animals, the human infant comes into the world very immature and helpless. Hence the period of youth is largely devoted to a perfecting of the various functions, and especially to the forming of associations and the laying out of paths of greater and less resistance within the central nervous system—in a word, to the formation of habits. Many functions vary in their activity periodically. As examples of such variations may be mentioned the common increase of weight in winter and decrease in summer, the monthly menstrual flow, a regular daily variation in temperature, such that the highest temperature occurs between 9 A. M. and 6 P. M., the lowest between 11 P. M. and 3 A. M., and a similar daily variation in the pulse rate and in the rate and depth of respiration.

Lifetime of Individual.

Of all the daily rhythms, the alternation of sleep and waking is the most striking. Sleep is, in brief, a profound depression of the activities

of the central nervous system. The muscular reflexes, the activities of the sense-organs, respiration, secretion by the glands, and general metabolism are all depressed, perhaps as the result of the central depression; but the absence of consciousness—that is, the depression of the activities of the psychic cells—is the most pronounced feature of sleep. That the psychic activity is not always wholly eliminated is evidenced by the occurrence of dreams, but the fragmentary and grotesque character of dreams indicates that but a few brain-cells are engaged in their production. The reason for this periodic depression of brain activity has been long sought, but with little success. Perhaps the accumulation within the body of the waste products of protoplasmic activity causes a temporary paralysis of the brain-cells, lasting until the wastes are removed. However this may be, the amount of blood in the brain is probably considerably less during the sleeping than during the waking hours, and this may of itself cause cerebral depression.

Sleep.

Sooner or later, even if disease and accident are safely overcome, the vital machine is doomed to wear out, and death follows. Physiologists recognise two kinds of death: death of the individual and death of the tissues. The individual dies when the heart ceases to beat and to supply the whole body with food and oxygen. But the individual tissues vary very greatly in the time of their death. The nervous tissues die almost immediately, but the muscles are capable of contraction upon artificial stimulation for a considerable time after the thinking man has forever ceased his activities. Probably not for several hours do all the chemical changes take place within the protoplasm that are the evidence of the passing away of that mysterious, unexplained condition that we are wont to call life.

Death.

CHAPTER VI.

HEREDITY.

In the vast world of life nothing seems more marvellous than the fact of inheritance. Like produces like; a child resembles its parents.

This fact is easily comprehensible in the one-celled organisms, where the parent cell, after a period of activity, puts an end to its individuality by an equal division of its whole body into two similar offspring, and nothing is lost. But in the higher and larger animals, composed of countless millions of cells that are specialized in a great variety of ways, the vital material contributed by the parents consists solely of the two microscopic germ cells,

Inheritance a Biological Fact.

and from this infinitesimal beginning there comes an organism that resembles, often in minute and unimportant details, the parents, the grandparents, and even remote ancestors, and that does not resemble other races. Here, if anywhere in our search after natural causes of things, it seems necessary to bring into causal relation the supernatural, and to hide our helplessness in an assumption of some mysterious guiding force that is distinct from vital matter and that we know not of. Truly, we know little of natural law, but the restless scientific spirit of man is ill content with a supernatural explanation of heredity. Inheritance is a biological fact, and must be explained in accordance with biological laws.

Facts of Inheritance.

Before proceeding, however, to the explanation, let us review in some detail the facts that must be explained. We have said that like produces like. This statement must be accepted with certain modifications. Obviously, no two individuals are like each other in all points; twins, indeed, may be "as like as two peas," and yet one is not the mirrored image of the other. As a general law, a child resembles its parents more closely than it resembles any other individual. Between its parents, the resemblance is in some cases more strongly in favour of the father, in other cases in favour of the mother; in still others, both paternal and maternal characteristics seem to be present in approximately equal proportions; rarely is the child "the exact image" of either parent. At times, however, the offspring seems to possess almost or quite none of the parental qualities, but to show likeness to grandparents or great-grandparents, either as regards general or as regards particular features or qualities. The reappearance of an ancestral quality thus, after having lapsed in one or more generations, is called *atavism* or *reversion*, and the subject forms one of the interesting chapters in the story of heredity. Lastly, in rare cases a child seems to be a veritable "black sheep," and to possess no qualities whatever that ally it to its progenitors. In speaking of inherited resemblances, we do not mean to confine ourselves to mere anatomical matters; likeness of feature, of form, of size, of structure, is most obvious, and is the kind of resemblance most commonly sought for. But likeness in things physiological and things psychological, in the mode of working of the body and of the mind, in things moral, in peculiarities of temperament, is as common, if not so readily perceived. In fact it is difficult, if not quite impossible, to draw the line between features and qualities of the parent that are heritable and those that are not so.

The question of the inheritance of disease has been much debated. It seems to be a fact that the germs of certain infectious diseases, such as syphilis, may be conveyed to the child's organism within the parent's germ cells, or even directly from the mother's body to the growing embryo. It seems also probable that predisposition to certain diseases, in the form

of constitutional weakness and diminished power of resistance to the disease germs, is heritable. Probably the apparent transmission of consumption is thus to be explained. Inherited predisposition and the fact that the child is usually brought up in the home of its consumptive parents, with every opportunity of acquiring the very germ that it can not successfully resist, are probably responsible for many attacks of this fatal malady. Predisposition to nervous diseases, to insanity, to suicide, and to crime, are certainly transmissible.

Inheritance of Diseases.

A second much-debated question is that as to whether new characteristics acquired by a parent may be transmitted to his child. To the mind of the layman, and at first thought the question seems superfluous, for apparently there are innumerable instances of such transmission about us—the affirmative side of the question goes without saying. But when we examine the evidence carefully we are surprised at its inconclusiveness. In one case the peculiarity is found, after all, to be not one acquired by the parent, but one possessed also by other ancestors—to be inherent in the race; in another case, what is inherited may easily be a tendency, a strength or weakness of mind or character, that with a suitable environment may show in the child in the same striking manner as in the parent, and yet that is in no sense an inheritance of anything acquired by the parent—such, for example, as a taste for strong drink; in another case, the parent's peculiarity may prove, upon examination, to have been obtained subsequent to the birth of the child! And thus, one by one, innumerable cases of seeming inheritance of acquired characters have been disproved. Experimental investigation has proved equally inconclusive. For centuries the Chinese have compressed and distorted the feet of their girls; yet the feet of Chinese girls born at the present time are apparently not different from those of a generation a thousand years ago. Numerous researches made in recent years upon the dehorning of cattle and the removal of the tails of mice for a long series of generations have resulted in no reduction of the horns in the one case or of the tails in the other. Hence, though there are still many seeming arguments in favour of use and disuse as important factors in evolution and in heredity, there are many persons that exclude these utterly from their creed, and so the matter of the inheritance of acquired characters must be left for the present undecided.

Inheritance of Acquired Characters.

In view of the above facts it seems idle, and it is certainly misleading, to talk of the equality of men, for Nature has established classes that are much more firmly ordained than are those of society. The environment of the child and the man has much to do with what the individual accomplishes in the world, but the environment works upon material that already is moulded in great part by past

Heredity powerful.

generations. The inherited qualities of one person place him at once well in advance in the struggle for existence; those of another too often prove a serious handicap. Heredity is a powerful factor in human progress. It is to be hoped that a greater knowledge of its facts and principles will gradually modify existing educational systems for the young and penal systems for criminals.

Germ-plasm.

How, now, may the above facts of inheritance be explained? Leaving aside all metaphysical and theological theories as unbiological and inadequate, we must start with the belief, incredible as it may seem, that the bits of protoplasm that constitute the ovum and the spermatozoön contain within themselves in some form the qualities of the mother and the father respectively, and to some extent of more distant progenitors. Probably we can go even further than this, for there is much evidence that the real carrier of the hereditary qualities, the *germ-plasm*, is confined to the nuclei alone of the two germ cells. We have already seen that the tail of the spermatozoön is a locomotor organ, and dies after conveying the head to the ovum; the head consists chiefly of nucleus, and it alone enters the egg. Likewise, within the ovum the mass of egg substance seems to subserve nutritive and other purposes, while the nucleus alone is probably essentially hereditary. The fusion of the spermatozoön and the ovum is a fusion of their nuclei, and the segmentation of the egg is primarily a nuclear phenomenon.

Darwin's Theory of Pangenesis.

But how is it possible for the minute germ-plasm to obtain and to hold the parental qualities? This problem has been the subject of much speculation, especially since the writings of Darwin set men to thinking of the origin of species and the mechanism of descent. In his book entitled *The Variation of Animals and Plants under Domestication*, published in 1868, Darwin gave to the world his own hypothesis of inheritance in a chapter entitled *Provisional Hypothesis of Pangenesis.* In brief, this theory supposes that all parts of the body are giving off at all times excessively minute particles, the germs of the various cells, or *gemmules*, as Darwin called them; these pass into the circulating blood, are carried to the reproductive organs, and become a part of the germ cells. Hence every germ cell is a mass of germs of the body cells of the parent, together with some gemmules of more remote ancestors, and hence the fertilized ovum contains the potentialities of the image of either parent and of some more ancient ancestral characteristics. Darwin's gemmules are somewhat of the nature of Herbert Spencer's hypothetical "physiological units," which, before Darwin wrote, were used by Spencer to explain heredity. Darwin's hypothesis allows the transmission of characteristics that are acquired by the parent; for an alteration of any part by use, disuse, loss, or injury might cause altered gemmules to go to the germ cells, and the

child might then show in the corresponding part of his body the effects of use, disuse, loss, or injury in the parent. Darwin's theory is purely speculative. Neither he nor later biologists have known, as an observed fact, any such giving off of germinal units as he assumes. The theory has not been generally accepted; for, apart from the inconceivability of the presence of so vast a number of germs within a single minute cell, many facts render it improbable. But it has served a useful purpose, as doubtless Darwin intended it should serve, in stimulating thought and investigation.

Weismann's Theory.

Since the appearance of Darwin's provisional hypothesis a large literature upon heredity has appeared, and several theories have been proposed. Some of these follow Darwin and attempt to supply lacks in his explanation; others are far removed from his speculations. We have here space to mention but one of these, which has attracted wider attention than any other, and which has been the subject of widespread and earnest discussion. This is the theory of Prof. Weismann, of the German University of Freiburg, who since 1881 has published several volumes of essays upon this and kindred subjects. Weismann is a careful and conscientious thinker. His theory has been developed gradually, and, as the significance of his main conceptions has broadened with continued thought and investigation, his later writings contain modifications of his earlier views.

The Continuity of Germ-plasm.

The nucleus of Weismann's theory is expressed by his own phrase, "*the continuity of the germ-plasm.*" This phrase means that, according to his idea, the germinal or hereditary substance that is present in the ovum or the spermatozoön of any individual, whether man, lower animal, or plant, has come directly from the germinal substance of the parent of the individual; that the germinal substance of the parent likewise has come directly from that of the parent's parent; that the germinal substance of any individual may be traced through parent, grandparent, great-grandparent, and so backward to the remotest ancestors; that, in a word, germinal substance, arising far back in the lowly and primitive predecessors of existing organisms, has been and is continuous in each line of descent throughout all generations. Hence, germinal substance does not arise *de novo;* it does not originate within a body by the concourse of multitudinous minute "gemmules" that are given off from all parts of the body, but it is derived solely from pre-existing germinal substance; in this sense all individuals are powerfully and equally "blue-blooded." Every individual, therefore, begins life as a minute mass of germ-plasm, that consists partly of male germ-plasm and partly of female germ-plasm, and that in the case of the human being is destined to grow and develop into the child within the mother's womb. As growth and development go on, much of

the germ-plasm differentiates, and produces the various cells, tissues, and organs of the child's body. A small portion, however, remains undifferentiated, and takes up its residence in the essential reproductive organ of the child—in the ovary, if the child be a girl, in the testis if a boy; and this undifferentiated residue which, as has been seen, has come directly from the parents, is the germ of the future progeny of the child.

Germ-plasm and Somatoplasm.

Hence, according to Weismann's theory, the body of every individual consists of two kinds of protoplasm, viz., *germ-plasm*, or hereditary substance, which in its undifferentiated form resides within the essential reproductive organ, and is the derivative of past and the progenitor of future races; and *body-plasm*, or *somatoplasm*, which is the protoplasm of the rest of the body, the muscles, the glands, the heart, and the brain. The latter serves the daily needs of the individual and dies when the individual dies. The former subserves reproduction alone; if the individual reproduces its kind, some of the germ-plasm is passed on to the descendant; if the individual does not reproduce, the germ-plasm dies with him, and that particular line of descent is forever ended.

Relation of Germ-plasm and Somatoplasm.

Thus far Weismann's theory seems readily comprehensible and reasonable. But let us carry it, as its author does, a little farther. What relation within an individual body do these two kinds of protoplasm—the germ-plasm and the somatoplasm—bear to each other? Do changes in the one necessarily affect the other? Weismann believes that the two are quite independent of and distinct from each other. They are nourished by the same nutrient blood and lymph, it is true, and any general alteration of the nutrient fluids alters the nutrition of the two alike; but this is of comparative unimportance. The important consideration is that any alteration of a particular part of the body-protoplasm does not affect the germ-plasm; in the origin of the latter from the parent's germ-plasm instead of from the individual's own somatoplasm, and in the absence of gemmules passing constantly from somatoplasm to germ-plasm, the latter can not reflect the condition of the former. Hence, the loss of a limb by accident, the gain of strength in particular muscles by athletic exercise, the acquisition of an art, like piano-playing, which consists of delicate and intricate muscular and nervous adjustments, the long-continued mental development of the man or the woman which carries with it molecular adjustments of brain substance, the practice of a trade or profession which develops abnormally certain organs, or tissues, or cells, and allows other organs, tissues, or cells to degenerate—all these affect the germ-plasm in no wise, and can not be transmitted to the descendants of the individual. Characteristics acquired by the parent are, therefore, not inherited by the child. The *non-inheritance of acquired characters* is

the second fundamental postulate of Weismann's theory, and is to be placed beside that of the continuity of germ-plasm.

Variation.

Why, then, are not all children alike mentally, morally, and physically? From a common origin in the early history of organic beings, with a descent through numberless generations by a continuity of germ-plasm that leads a charmed life of a certain degree of independence of environmental changes, how is variation possible, and how may the differences of individuals and of races be accounted for? In the first place, germ-plasm is not wholly independent of environmental changes. It is capable of, and is constantly undergoing, alteration as the result of general nutritional alterations taking place in the body in which it is housed. The germ-plasm of one line of descent must therefore necessarily differ somewhat from that of another line of descent, since the environment of the one differs from that of the other. In the second place—and here we have the chief source of variation—the individual is the result of a fusion of two varieties of germ-plasm, that of the father and that of the mother, each with a history and capabilities differing from those of the other. Therefore the resultant organism, while possessing ancestral qualities, must possess them in a combination that has never before existed; it must differ from any organism that has preceded it; and hence it follows that no two individuals, or two species, or two races can be alike.

These, then, are the elements of Weismann's theory: continuity of germ-plasm and non-inheritance of acquired characters tending to preserve the uniformity of the race; slight germinal changes and sexual reproduction tending to destroy that uniformity.* During the past ten years and more the theory in its manifold details has been fought over with great vigour by its friends and its foes. The contest has been especially warm over the question of the inheritance of acquired characters.

We have thus touched very incompletely upon some of the principles and problems and attempted explanations of the mystery of inheritance. To the scientist a mystery is always inviting, and to the modern biologist that of heredity is especially so. What is needed most is careful, truthful observation and recording of the facts that are all about us, and well-directed, painstaking and unprejudiced physiological experimentation as to hereditary possibilities. Darwin, Galton, Weismann, and others have done much of the former service; the latter belongs largely to the science of the future.

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* *Essays upon Heredity and Kindred Biological Problems.* By August Weismann. Authorized translation. Vol. I, 1889; Vol. II, 1892. Oxford, The Clarendon Press.

The Germ-plasm: A Theory of Heredity. By August Weismann. Authorized translation. 1893. New York, Charles Scribner's Sons.

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